U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-291 786

A Handbook for the Assessment of Environmental Benefits and Pollution Control Costs

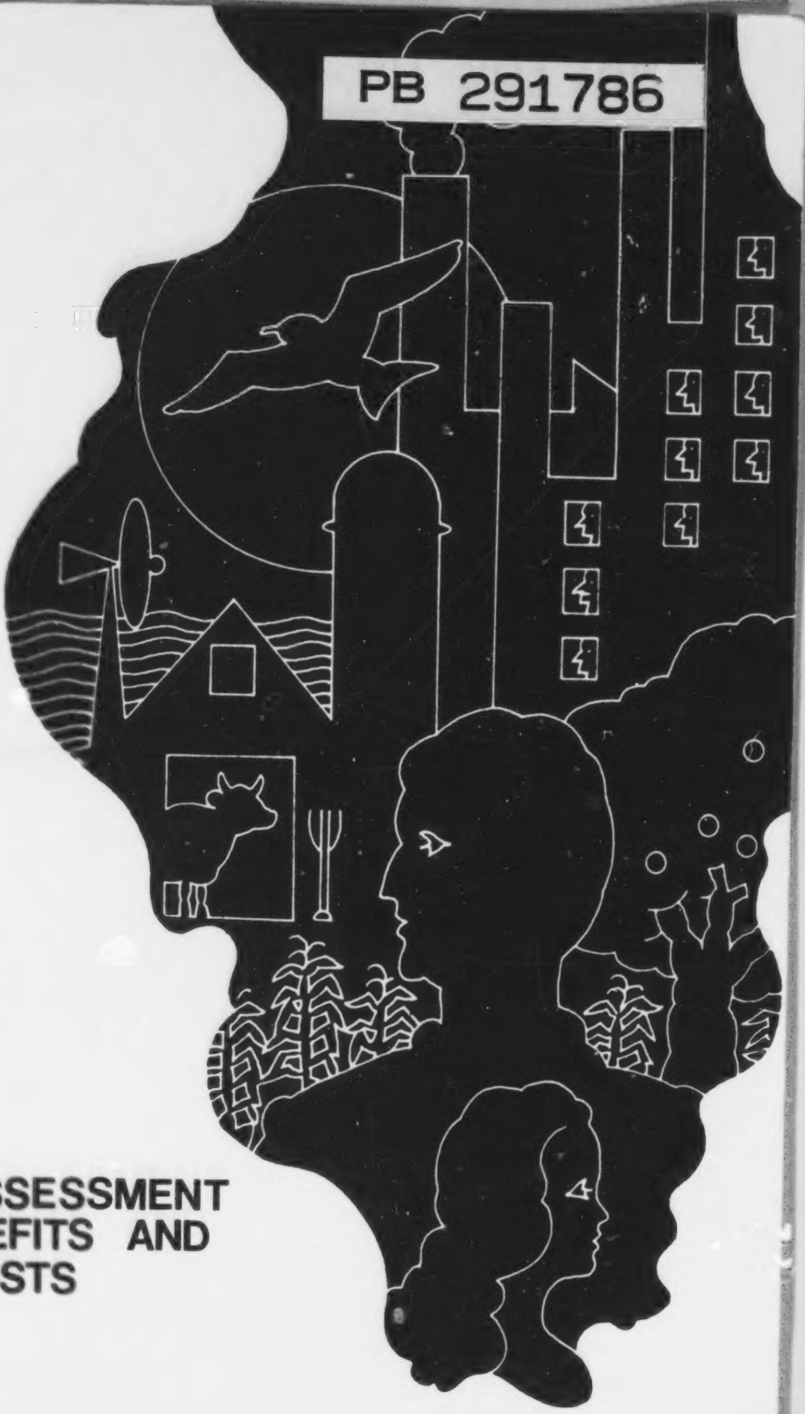
Illinois Inst of Natural Resources, Chicago

Aug 78

PB 291786

IINR

ILLINOIS
INSTITUTE OF
NATURAL RESOURCES



A HANDBOOK FOR THE ASSESSMENT OF ENVIRONMENTAL BENEFITS AND POLLUTION CONTROL COSTS

Document No. 78/29

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

BIBLIOGRAPHIC DATA SHEET

1. Report No. INR 78/29

2.

3. Recipient's Accession No. PB291786

4. Title and Subtitle
A Handbook for the Assessment of Environmental Benefits and Pollution Control Costs

5. Report Date 8/1978

6.

7. Author(s)
L. Babcock, et.al.

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Decision Analysis Task Force
Illinois Institute of Natural Resources
309 W. Washington St.,
Chicago, IL 60606

10. Project/Task/Work Unit No. 90.012

11. Contract/Grant No.

12. Sponsoring Organization Name and Address
Ill. Institute of Natural Resources
309 W. Washington St.,
Chicago, IL 60606

13. Type of Report & Period Covered Final

14.

15. Supplementary Notes

16. Abstracts

This Handbook represents the first attempt at outlining and describing the assessment methods available to writers of economic impact studies. It is presented in loose-leaf form because we expect it to change. Like the state-of-the art itself, its contents will adjust to the growing knowledge and experience of those who utilize it.

Contents include ——— (to pg iii)

17. Key Words and Document Analysis. 17a. Descriptors

BENEFIT COST ANALYSIS
POLLUTION

17b. Identifiers/Open-Ended Terms

Economic Impact Statements - Illinois
Economic Impact Studies - Illinois

17c. COSATI Field/Group 14A Cost Effectiveness 13B Civil Engineering

18. Availability Statement
Unlimited Distribution sponsored by U.S. EPA

19. Security Class (This Report) UNCLASSIFIED

20. Security Class (This Page UNCLASSIFIED

21. No. of Pages 174

22. Price PCA08 / MF A01

FORM NTIS-35 (REV. 3-72)

THIS FORM MAY BE REPRODUCED

USCOMM-DC 14952-P72

DOC. NO. 78/29
August, 1978

A HANDBOOK FOR THE ASSESSMENT OF ENVIRONMENTAL BENEFITS AND POLLUTION CONTROL COSTS

by the

Decision Analysis Task Force

L. Babcock
K. Croke
A. Hurter
P. Loquercio
H. Roberts
H. Sievering, Chairman
G. Tolley

PROJECT OFFICER: PETER LOQUERCIO
Project No. 90.012

Frank Beal, Director

Peter Loquercio, Director
Division of Environmental
Management

State of Illinois
Institute of Natural Resources
309 West Washington Street
Chicago, Illinois 60606

NOTE

This report has been reproduced as received from the contractor. No editorial or other changes have been made. Conclusions expressed are those of the contractor.

Printed by Authority of the State of Illinois

Date Printed: August, 1978
Quantity Printed: 500

This document has been cataloged as follows:

Babcock, L., et al
A Handbook for the assessment of environmental benefits and pollution control costs / by Decision Analysis Task Force; L. Babcock, K. Croke, A. Hurter, P. Loquercio, H. Roberts, H. Sievering, (and) G. Tolley. -- Chicago : Illinois Institute of Natural Resources, 1978.

169p. 28cm. -- (Doc. No. 78/29)

1. Economic Impact Statements - Illinois. 2. Benefit assessments. 3. Benefit considerations - Methods. I. Title. II. Croke, K. III. Hurter, A. IV. Illinois Institute of Natural Resources. Division of Environmental Management.

IINR Environmental Information Center

Illinois Institute of Natural Resources
309 West Washington Street
Chicago, IL 60606
(312) 793-3870

(from BDS)

(Economic impact statement)

TABLE OF CONTENTS

Page

1. Preface 1
2. Chapter I: The Legal Basis Of An Ecis 4
3. Chapter II: How To Design An Ecis 8
4. Chapter III: Environmental Quality Analysis (including 34
5. Chapter IV: (a) Environmental Benefit/ Damage Assessment and 77
   (b) The Impact Of Pollution On Residential Property Values 81
6. Chapter V: Pollution Control: Cost Estimation and 131
7. Chapter VI: Prices, Output And Employment 151

PREFACE

Why was this work done? The story begins in 1975. The Illinois General Assembly enacted a law to require the economic evaluation of all proposed environmental regulations. Responsibility for preparation of the new economic impact studies was assigned to the Institute for Environmental Quality, a State agency charged with investigating the practical problems of environmental management. Under the law, the IEQ's economic analysis must address both the economic and environmental costs and benefits of proposed regulations. Thus, their authors often face the difficult task of defining the unclear relationship between environmental quality and quality of life. Health effects, use and property values are a few of the factors which must be explored. The impact studies also evaluate changes in employment, output, and prices. Although quantification of these latter impacts seems more straightforward than the calculation of environmental benefits, considerable uncertainty characterizes all the assessments.

To provide guidance and counsel to the Institute, the Legislature established an Economic Technical Advisory Committee (ETAC) with representatives from agriculture, local government, commerce, industry, labor and public health. The Committee evaluates the impact studies-called economic impact studies or ecis-to determine if they comply with the strict provisions of the law. It must vote its approval before a report can be transmitted to the Pollution Control Board (PCB), where a final decision is made. However, the Board cannot issue a ruling until it has held public hearings on the study.

From proposal to decision, a regulatory proceeding involves interplay between many groups, including legislators, public interest groups, industry spokespeople, and of course the PCB itself. It is imperative that these groups communicate accurately and freely with each other if the best decisions are to be made. To promote the necessary common language, the Decision Analysis Task Force (DATF) was organized. The Institute directed the DATF to devise a methodology for decision making, a task which causes special problems because of the subjective character of many environmental trade-offs. In particular, the DATF was asked to design a technique which defined the parameters of uncertainty and risk and applied objective criteria to the decision-making process. (While the IEQ, later known as the INR for Institute of Natural Resources, accepts the premise that public decision-making will never be totally objective, we feel that development of the state-of-the-art will produce more "balanced" decisions.)

The Decision Analysis Task Force consists of Lyn Babcock, Professor of Environmental Health Science and Engineering, School of Public Health, University of Illinois, Kevin Croke, Professor of Health Resource Management, School of Public Health, University of Illinois, Art Hurter, Professor of Industrial Engineering and Management Sciences and Finance, Northwestern University, Howard Roberts, Professor of Environmental Science, Governors State University, George Tolley, Professor of Economics, University of Chicago and Herman Sievering, Professor of Engineering Science, Governors State University and Chairman of DATF. The DATF has moved along several fronts to achieve the goal set out for it.

One result of the first 18 months work is this Handbook for Economic Impact Assessment of Environmental Regulations. All members of the Task Force have contributed to this Handbook. Chapter One looks at the social and legal setting in Illinois which gave "birth" to the ecis (authors: K. Croke, H. Roberts and H. Sievering); chapter Two reviews the basic elements that must be considered in the "production" of an ecis (authors: K. Croke and G. Tolley); chapter Three describes the essential steps needed to make good use of environmental models in the context of ecis (authors: H. Roberts and H. Sievering); chapter Four puts forth specific methodology to be used in human health, property value and other benefits assessments (authors: K.Croke and A. Hurter); chapter Five addresses pollution control cost estimation (author: L. Babcock); and chapter Six discusses price impacts of environmental regulation (authors: K. Croke and A. Hurter).

This Handbook, then, represents the first attempt at outlining and describing the assessment methods available to writers of economic impact studies. It is presented in loose-leaf form because we expect it to change. Like the state-of-the art itself, its contents will adjust to the growing knowledge and experience of those who utilize it.

Peter Loquercio, Director
Division of Environmental Management
Institute of Natural Resources (INR)

Herman Sievering, Chairman
Decision Analysis Task Force

Michael Friedman
Institute of Natural Resources (INR),
Staff Member in charge of the Economic
Impact Statement Program

CHAPTER ONE: THE LEGAL BASIS OF AN ECIS

Environmental pollution is causally related to certain damages borne by society. Human health effects such as increased incidence of respiratory disease due to air pollution, cancer induced by organic chemicals in water supplies, nervous disorders caused by excessive noise, and many others are of deep and important concern. Other damages related to the quality of recreational opportunities, reduced crop yields, climactic modification, soiling of buildings and materials, and decreased property values have also been documented. Protection of the public interest has dictated certain rules and regulations which are intended to decrease pollution and thereby its damages. Since the causal relationship is a direct one, the difference in damages before and after enforcement of the regulations should represent their benefits to society.

In order to gain these benefits, however, society must pay the associated direct costs of pollution control and deal with possible secondary economic impacts such as unemployment, industrial migration, and reduction in productive capacity among others. In the past, the rationale for incurring these costs appeared obvious in that the damages were often pervasive and acute. Public opinion demanded action to alleviate the burdens of pollution. Economic impact was recognized but not dealt with in a systematic, organized way. In general, it was left to regulatory agencies such as the IEPA to use various administrative procedures such as variances and differential enforcement schedules to help mitigate adverse economic impact.

A combination of several factors has caused a greater awareness of economic impact of pollution regulations. Conditions for the economy as a whole have changed. In the wake of the national energy shortage, costs of compliance have become more dominant. At the same time, due to the earlier regulations, some progress in pollution abatement has been achieved. This has softened the public outcry to some extent and has decreased the marginal value of further regulation.

Because the decisions are not as obvious as they once were, planners, legislators, and responsible decision-makers such as the Illinois Pollution Control Board (PCB) need to have a more sensitive method for evaluating benefits and costs of regulatory decisions. This need was recognized in Illinois in the form of recently enacted legislation.

On October 1, 1975, Illinois Public Act 79-790 (P.A.79-790) became law. It amended Section 6 and Section 27 of the Environmental Protection Act by adding Sections 6(b), (c), and (d) and Section 27(b). The requirements established by these amendments were such as to make Illinois unique among the 50 states in calling for an economic impact study to be conducted for pollution control regulations.

When evaluating economic impact, it is essential to maintain a balanced view by considering both costs and benefits of any proposed action. This is not only sound managerial practice, it is also a legal requirement as established in P.A. 79-790. Specifically, Section 6(b) states:

"The Institute shall prepare and publish a comprehensive study of the economic impact of the existing rules and regulations of the Board, in accordance with the criteria established in this subsection (b) of Section 6. Each economic impact study shall include, but not be limited to the following:

(i) An evaluation of the environmental costs, and benefits of the rules and regulations to the people of the State of Illinois, including the health, welfare and social costs and benefits.

(ii) An evaluation of the economic impact of the rules and regulations on the people of the State of Illinois, including but not limited to the effect of said rules and regulations on the following:

(a) cost of goods, and services,
(b) availability of goods and services,
(c) availability of employment

(iii) An evaluation of the economic impact of the rules and regulations on Illinois agriculture, including but not limited to the following:

(a) cost of food,
(b) availability of food, and
(c) availability of employment.

(iv) An evaluation of the economic impact of the rules and regulations on units of local government, including but not limited to the following:

(a) effect on local taxes,
(b) effect on local services, and
(c) effect on local community expansion.

(v) An evaluation of the economic impact of the rules and regulations on commerce and industry, including but not limited to the following:

(a) effect on prices,
(b) effect on expansion of industry in Illinois,
(c) effect on the availability of adequate supplies of energy, and
(d) effect on the attraction of new industry . . ."

Of particular concern under Section 6(b) is (i) above which calls for" . . .evaluation of the environmental costs and benefits of the rules and regulations . . . .". Thus, while the major portion of 6(b) details the kind of economic impact information to be included in an economic impact study (ecis), it retains recognition that such impacts must be balanced against the effects on"health, welfare, and social costs and benefits". In effect, what P.A. 79-790 calls for in 6(b) (i) is an environmental assessment of the consequences of pollution regulatory actions within the context of an overall economic impact study.

This Handbook is intended to provide a succinct description of methods useful for conducting the economic impact study. Specific methodological problems considered are environmental control costs, impact assessment damage analysis and the economic incidence of the regulation. Other work sponsored by the Illinois Institute for Environmental Quality has generated A Guide to Environmental Benefits Assessment in Economic Impact Studies (IIEQ Docu. #77/32). This Guide provides an analytical framework for the design and implementation of environmental benefits estimation as well as a format for the presentation of estimated benefits. Additional work seeks to improve the ways in which the ecis and the quantified results therein are used in regulatory decision making.

This Handbook,then, is part of a comprehensive effort to respond effectively to the requirements of P.A. 79-790.

CHAPTER TWO: HOW TO DESIGN AN ECIS

Introduction

The purpose of an ecis is to aid the Pollution Control Board in its deliberations on proposed environmental regulations. The role of an ecis as evidence in a regulatory setting places a burden on the contractor to produce a study which is defensible under cross-examination, which must be completed by a certain deadline, and which must be structured to act as an integral component of a larger body of evidence under consideration by the Pollution Control Board.

Meeting these requirements is made difficult by several considerations. Estimates must be made based on physical and economic relationships about which knowledge is limited. The available data invariably have many deficiencies. The relative importance to be attached to different effects of a regulation is often in doubt, especially during the early stages of investigation when an ecis is designed.

An ecis is used in a group decision-making process involving several different participants including the Pollution Control Board, the Economic and Technical Advisory Committee and interested or affected parties who participate in hearings. The findings of an ecis may come under adversarial attack, focusing attention on particular parts of the analysis which can receive needed attention in the design of the ecis if controversial points are anticipated. This need must be met without unduly sacrificing quality of the overall analysis. In the course of carrying out the analysis for an ecis and also in the course of the hearing process, findings may come to light suggesting a need to change the proposed regulation.

The contractor must try to foresee the nature of the possible changes in a proposed regulation and to analyze their effects.

In view of the limited funds available to carry out an ecis, difficult choices as to areas of emphasis and degree of refinement must be made. The choice of techniques as well as the task of write-up and presentation must take account of the fact that the Pollution Control Board and not the contractor will make the regulatory decision, subject to the prior review of the ecis by ETAC as well as a hearing process. The ecis must be understandable and acceptable to those whose background in many areas is at the lay level. Those who will use the ecis must understand the reasoning that leads to the findings, and they must be able to gain a sense of the reliability of the results. Particular care needs to be given to testing the sensitivity of results to ranges allowing for data and knowledge limitations and to conveying the findings about sensitivity objectively without discrediting the results.

Other design problems occur because the execution of an ecis is bound to involve at least economic and engineering expertise and probably a number of other disciplines, so that study design questions arise with respect to personnel requirements. Involving too many disciplines will make the study prohibitively expensive, while too few may lead to serious oversights.

In the present chapter, the design problems facing an ecis contractor are explored. The next section of the chapter outlines the major tasks necessary to complete an ecis. This is followed by a section detailing various pitfalls that have been encountered in previous ecis work and then a section discussing partially saving graces that can help avoid the pitfalls by making use of previous experience and staff guidance. The next section after that considers ways of dealing with four major design questions that shape an ecis. These questions pertain to the number of policy options that are to be assessed, the degree of detail in the study of benefits and costs, the handling of uncertainty and the disciplinary mix. The final section of the chapter indicates how to use the remainder of this Handbook in carrying out an ecis.

Overview of Tasks. A logical plan for carrying out an ecis is suggested by the processes through which emission sources and receptors, and through them the economy, are affected by environmental regulations. The plan indicated by these processes is shown in Figure 1.

First, as shown in the upper left box, emissions or other actions affecting the environment are controlled, requiring attention to pollution at its sources. Second, as shown in the middle box, the controls result in environmental quality that must be estimated. Third, as shown in the upper right box, the environmental quality changes result in reductions in environmental damages which are benefits of the regulation. Fourth, in light of the preceding steps and as shown in the box in the lower part of the figure, the control costs and environmental benefits have impacts on producers, consumers and local governments.

While the tasks required to complete an ecis will of course vary from one regulation to another, each of the major elements of the plan just presented will almost certainly have to be included. Following the suggested format will contribute to a

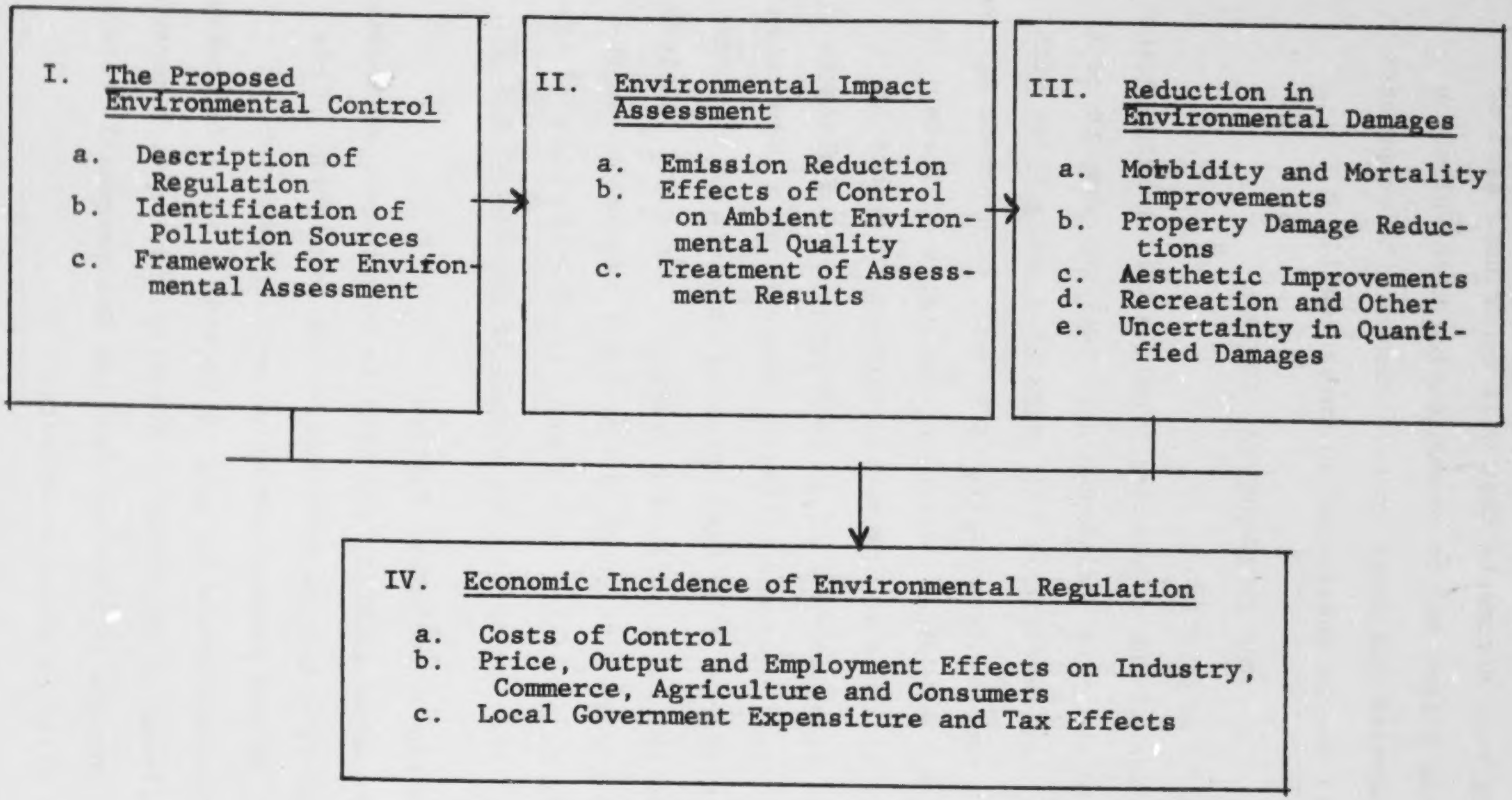

I. The Proposed Environmental Control
a. Description of Regulation
b. Identification of Pollution Sources
c. Framework for Environmental Assessment
II. Environmental Impact Assessment
a. Emission Reduction
b. Effects of Control on Ambient Environmental Quality
c. Treatment of Assessment Results
III. Reduction in Environmental Damages
a. Morbidity and Mortality Improvements
b. Property Damage Reductions
c. Aesthetic Improvements
d. Recreation and Other
e. Uncertainty in Quantified Damages
IV. Economic Incidence of Environmental Regulation
a. Costs of Control
b. Price, Output and Employment Effects on Industry, Commerce, Agriculture and Consumers
c. Local Government Expensiture and Tax Effects

FIGURE 1

Organization Plan for Ecis

uniformity among ecis documents that will contribute ease of comparisons among ecises and to communication with Pollution Control Board members and other users. Each of the components of the plan will now be considered in more detail.

I. THE ENVIRONMENTAL CONTROL

a. Description of Regulation

A description of the regulation provides the starting point for the economic analysis. Although this task may seem to be a straightforward one, experience has shown that ambiguities with respect to what constitutes compliance or what enforcement actions are required can yield widely different estimates of costs. For example, if the Illinois Enviornmental Protection Agency in response to the establishment of a discharge standard plans to inspect all sources on an annual basis, the cost of a regulation would be very different from that which is involved in bi-annual surveys of only the major pollution sources. Therefore, a clear wording of the interpretation of the proposed regulation is required in order to provide a firm foundation for the rest of the investigation. The interpretation should be checked with IIEQ.

b. Identification of Pollution Sources

One of the major tasks in any ecis is to generate an inventory of pollution control sources affected by the regulation. This should pertain to the present situation and, in addition, if feasible projections should be made to provide a basis for carrying out an analysis of the future. Normally, information regarding pollution sources is obtained from the Environmental Protection Agency permit files or emission inventory.

c. Framework for Environmental Assessment

Once the pollution inventory is considered complete a second inventory to identify environmental impacts must begin. To arrive at a sufficiently quantified assessment of the regulatory benefits of reducing these impacts several stages must be successfully completed. These include: the identification of the range of environmental impacts affected by the regulation; the ambient environmental quality analysis, the damage reduction analysis; the benefits assessment; and the presentation of assessment results so that the decision maker can appreciate the limitations and assumptions underlying the analyses and assessment. Limited time and funds require the contractor to make choices and obtain assistance wherever possible to still arrive at a benefits assessment.

Several aids are available. During the identification stage the computer cross referencing system (available through the IIEQ library) will help not only delineate the range of impacts to be considered but also will provide a list of references to pursue the accurate description and quantification of impacts identified for further consideration. During the quantification stages of ambient quality analysis damage reduction and benefits assessment both this Handbook and the Guide to Environmental Benefits Assessment in Economic Impact Studies (IIEQ Docu.#77/32) should be especially helpful. Finally, the Benefits Assessment Worksheet, described in Chapter 6 of the Guide should facilitate communication between the contractor's assessment results and the decision-maker.

II. ENVIRONMENTAL IMPACT ASSESSMENT

This component of the analysis is concerned with the estimation of the environmental impacts occurring if the proposed regulation is adopted.

a. Emission or Effluent Reduction

The geographic distribution of the impacted sources will need to be identified, and the change in emissions, effluents or other actions affecting the environment will need to be quanified. This will require an estimate of the present and expected levels of emissions if the regulation is not adopted and the level that will be achieved under the regulation.

b. Effects on Environmental Quality

One of the major tasks involved in assessing effects on environmental quality is to relate the emission or effluent reductions at the pollution sources to environmental quality in affected areas, by means of environmental quality models. The selection, data acquisition and analysis using these models can constitute a major element of the study.

c. Treatment of Assessment Results

Once completing the environmental quality analysis the contractor is in an exceptionally good position to judge which environmental impacts can be analyzed for quantitative damage. Because data may be lacking the environmental quality analysis may only have identified whether a substantial or insignificant change in environmental quality may result from promulgation of the proposed regulation. The contractor may be forced to state a quasi-quantitative benefit regarding that environmental factor. Hopefully, the data base and environmental quality analysis will allow the contractor to pursue a detailed quantitative benefit assessment. As this quantification progresses the physical damage reduction, uncertainties in its calculation and assumptions underlying its development should be conveyed succinctly.

This is also true for any dollar valuation of the physical damage reduction. To provide a simple mechanism for the contractor to do this and to provide a standard method for presentation of environmental assessments to the decision process the Assessment Worksheets (referred to earlier) are to be used.

III. REDUCTIONS IN ENVIRONMENTAL DAMAGES

Once the environmental quality changes due to the regulation have been assessed, the contractor is required to determine of what value to society these changes are. This is the area of benefit assessment and can pose the most difficult problems of the study, depending on the nature of the regulation. Occasionally, for reductions in property damages, the estimation and measurement of value of the reduction in damages is fairly straightforward and can be directly inferred from cost calculations, such as reductions in repairs or painting costs resulting from better environmental quality. For morbidity, mortality, aesthetic, recreation and other effects, determination of the value or tradeoff that it is worthwhile to make can be considerably more difficult. Various techniques have been developed for inferring on the basis of market behavior, real estate values, travel costs borne or other behavior what the willingness to pay of people is for various environmental damage reductions. Some of the work on damage reductions involves estimating benefits attached to low probability events. Because the uncertainty in valuation can be significant statement of the degree of uncertainty should accompany all quantified damages.

IV. ECONOMIC INCIDENCE OF THE REGULATION

a. Costs of Control

After the inventory has been established, an investigation of the available control technology or strategies must be made in order to determine what responses different sources may make in coming into compliance with the proposed regulations. The contractor must then determine which source categories will adopt specific control technologies and what the costs of adopting these technologies will be.

b. Price, Output and Employment Effects

Since any proposed regulation will require compliance costs to be incurred, it is to be expected that these costs will in some way alter the behavior of those incurring them with effects on pricing, output and employment decisions. This explains the causality arrow from Box I to Box IV in Figure 1. Firms required to install pollution control devices will find their cost of doing business is increased and may be expected to pass on all or part of the increase in the form of higher prices. If the firm produces intermediate products, the price increases may be passed on to still other products which use the product in question as an input. The raising of price may induce consumers to reduce the amount of purchases or may disadvantage the position of Illinois firms relative to competitors in other states, leading to reductions in output in Illinois. If the reductions in output are severe enough, there may be unemployment effects whose magnitude and duration is to be estimated in the ecis. The output and employment effects include secondary impacts due to local multiplier effects. The estimation of incidence will require attention to the extent to which effects come to be lodged in land values, labor returns or capital returns.

The same kinds of economic incidence effects of costs just discussed may occur for reductions in environmental damages, which is to say there may also be economic incidence effects of the benefits of the regulation. The incidence effects of the benefits will generally be in the opposite direction, e.g. prices of benefited products may fall and their output may rise. In addition, costs and inconvenience borne by residents may be reduced making Illinois a more attractive place to live. The existence of incidence effects of the benefits of the regulation explains the causality arrow from Box III to Box IV in Figure 1. Any such incidence effects found to be significant should be estimated in quantitative terms.

As noted in Chapter One, the law requires that the estimation of price, output and employment effects be comprehensive, including attention to industry, commerce, agriculture and consumers.

c. Local Government Effects

Effects of a regulation on the amount of economic activity and unemployment in Illinois may have repercussions on local governments, affecting both tax revenues and services provided by governments. For instance, if a regulation results in there being less output of some industries in Illinois than without the regulation, there will be less tax revenues. Concomitantly, less government expenditures will be needed to provide services to businesses and people who will be in the state. If the decline in tax revenues is greater than the decline in expenditures, a burden will be placed on the people remaining in the state. One reason for a greater decline in taxes than revenues would be the existence of fiscal surpluses for some businesses or individuals whereby they pay more in taxes than they receive in services from local government. Another reason could be economies of scale in providing services. For instance, roads have a large element of fixed costs. If a firm leaves the state, the resulting decline in gasoline tax revenues and other revenues available for roads may be significant while there may be a negligible decline in expenditures needed to maintain the road network.

A regulation need not necessarily have any significant effects on local government. A preliminary check of likely significance should be made in the design phase of the ecis in order to determine the extent of attention needed to these effects.

Some Pitfalls to be Avoided

In carrying out the suggested plan for the ecis, the quality of the final product can be improved by avoiding pitfalls that have been encountered in past environmental analyses. Some of these will now be discussed, proceding from the more to the less obvious.

1. Bias. One reason there is room for bias, e.g. about whether a proposed regulation should be made to look favorable or unfavorable, is the necessity to use professional judgment in making estimates. Bias can also enter in the choice of what to quantify and in emphasis given to various parts of the analysis. For instance, aesthetic benefits of a regulation might be described

glowingly in qualitative terms, making the regulation look attractive with no serious attention to how society values these effects relative to the costs of the regulation. As another example, the onerousness of compliance has sometimes been played up without quantification.

The most serious problems of bias have not to do with conscious bias, which is easy to combat and probably rare, but with unconscious bias. Besides the investigator's predilections, there may be a problem of unconsciously weighting the results toward the interests which it is felt will do the most effective job in the hearing process and so minimize the likelihood of the results being attacked. Over and above maintaining steadfast dedication to objectivity, it should be remembered that in the course of the decision-making process equal or better expert judgment may be brought to bear unpredictably from any side which will thoroughly expose the bases for the estimates.

2. Forcing a Conclusion. Quite apart from bias, an investigator may become convinced in the course of conducting the ecis study that a regulation either is or is not justified and may, again unconsciously, frame the analysis and exposition to force this conclusion. An extreme form of this pitfall is the presentation of a single benefit cost ratio as the major conclusion of a study which suggests that the regulation is justified if the ratio is greater than one and unjustified if it is not. The Board being the decision-making body has as its perogative the reaching of summary conclusions about benefits and costs. It needs the underlying information which will indicate the sensitivity of benefit

and cost estimates to knowledge and data limitations as well as general economic uncertainties which are imbedded in investigator assumptions. The Board has the perogative to change any of the assumptions that it does not agree with and to come to an entirely different conclusion if that is its judgment. Even if it agrees completely with the benefit and cost estimates, any regulation will have its own unique income distributional effects as reflected in the economic incidence of the regulation. Even though the aggregate of benefits and costs indicates a clear decision as to whether the regulation is justified, some groups may have imposed on them large losses (or gains) which is a distributional consideration not reflected in overall benefit and cost comparisons. The Board may decide that such distributional considerations are of sufficient importance to over-ride conclusions based only on comparisons of total benefits and costs.

In short, the purpose of an ecis is to offer evidence relevant to reaching a conclusion, not itself to reach conclusions about the desirability of regulations.

3. Over-definiteness. The worst ecis is one which reaches seemingly highly definite conclusions about largely irrelevant effects based on the presentation of mostly descriptive material and applying overly refined techniques to unimportant effects, ignoring or minimizing the most consequential effects of the regulations. The pitfall of over-definiteness and the three pitfalls to be discussed immediately following are largely responsible for this worst kind of ecis.

Over-definiteness comes from choosing to concentrate on those effects about which there is little uncertainty, downplaying uncertainty attached to such quantitative estimates that are presented, and ignoring or minimizing the importance of effects which are difficult to estimate with precision. An ecis report which appears to present highly definite estimates may appear superficially to be successful. Yet it hinders the reaching of decisions. The very essence of making difficult decisions is that they must be made in the presence of uncertainty about outcomes, which must be conveyed fully to the Board.

4. Concentration on Irrelevant Descriptive Material. At the same time that any ecis is likely to raise difficult estimation problems that it may be tempting to duck, there usually exists a large volume of data that is considered to be at least vaguely related to any given ecis. Thus, some ecises have been loaded, or even padded, with data that overwhelms the reader. Upon closer scrutiny, one finds only a small percentage of the data actually useful to the overall evaluation.

5. Choice of Techniques Familiar to the Contractor Rather than Needed Techniques. Every investigator has his own disciplinary tools in which he has specialized. He is unlikely to be an expert in all the disciplines required in any one ecis. It is tempting to concentrate on what one knows and to leave out important effects if they require unfamiliar tools. A brief review of many environmental and economic impact assessment techniques is contained in this Handbook as well as the Guide referred to earlier.

6. Avoidance of Difficult-to-Quantify Effects. Closely related to the previous pitfall, there may be important effects, e.g.

aesthetic effects, which are difficult to deal with even given the best competences from all disciplines. These are often described glowingly or, alternatively, minimized rather than undertaking serious analyses of them, even though these may be the most important consideration in whether the regulation is justified. Presentation of all benefit effects on the assessment worksheet is considered essential.

7. Little or No Incidence Analysis. Because information on compliance costs is generally available in some form and because serious estimation of the incidence can be a difficult chore, there may be a tendency to assume that the incidence analysis is completed when the cost information is obtained. Thus estimates of price, output, employment and local government effects resulting from the costs may be made casually or omitted altogether. As brought out in Chapter One, the law requires that there be attention to these effects, and it gives prominence to them.

8. Overly Technical Presentation. Even when concepts used are not controversial to the Board, professional analyses are often presented in terms which the Board cannot understand. This problem tends to be inversely severe to the quality of the ecis, since a good ecis will use some technically refined approaches. The expositional problem has been continually under-estimated in the ecis process.

Saving Graces

There are not many offsetting aids to the foregoing list of pitfalls, but there are a few. First, experience with the ecis process is accumulating. Taking care to draw on the good examples of previous ecis work and not the poor examples, the contractor can utilize and build on the best of what has gone before. The remaining chapters of this Handbook attempt to aid in this respect. Second, the transcripts of Board hearings on related or similar matters can give guides to the contractor on issues that are likely to come up and on stances of the Board and others toward these issues. Third, staff at IIEQ and the Illinois EPA can provide valuable guidance and ideas based on their on-going familiarity with the ecis process. Studies should be carried out in close consultation with them.

Shaping the ecis: Four Major Design Questions

Being aware of the pitfalls that have been discussed and being armed with knowledge of past ecis experience and staff guidance related to the proposed regulation are preliminaries to proceeding to carry out the ecis tasks displayed in Figure 1. Common to accomplishing the tasks are certain major design questions which the contractor must assess in making a proper allocation of his budget to successfully perform the study. Four major questions may be identified.

(A) How many policy alternatives must be assessed in order to provide the Pollution Control Board with sufficient information to analyze the proposal?

Policy alternatives are defined here as being a collection of assumptions with regard to the nature of the regulation. These include the stringency of the regulation, its comprehensiveness, compliance schedule and the like.

The design problem with respect to the number of policy alternatives to be analyzed can be resolved in a number of ways. One viewpoint would be to simply evaluate the benefits and costs of the proposed regulation. If alterations to the proposal are made during the hearing process, then these would have to be evaluated at a later date or in a different set of hearings. A second procedure might be to evaluate the proposed regulation together with minor adjustments to the regulation in order to assess the effect and direction of small changes in the regulation on the costs and benefits associated with it. For example, if a maximum lead standard were proposed at X parts per million, the contractor could analyze the costs and benefits of the proposal, together with the costs and benefits of a hypothetical proposal which sets the standard at 90% and 110% of the proposed standard. A third option is to assess the proposal and one "challenger" proposal. The challenger proposal may be developed after discussions with groups which are likely to oppose the proposal. Thus, if the EPA proposes a lead standard at X parts per million, discussion with industrial groups may indicate that a challenger proposal involving a standard of Y parts per million may find much greater acceptance in the industrial circles. Thus, the evaluation of the proposal and one challenger would tend to crystallize those issues which will be brought before the Pollution Control Board during its formal hearings. A fifth option is to evaluate the proposal over a broad range of options in order to generate a cost/benefit relation showing the effect of wide variations of the stringency of the proposed regulations. Such an approach implicitly assumes that the Pollution Control Board will assess not only small changes to the regulation or changes proposed by groups having challenging positions, but also may take the initiative in making and promulgating a regulation which is significantly different than that which was proposed.

The choice among these alternatives will depend upon the situation and context of the particular proposal being made. The cost of the analysis will increase, of course, as one moves from evaluating just the proposal to the case in which a wide range of alternatives proposals are being evaluated. The contractor should have a clear understanding in the initial stages of the investigation with regard to the extent of the regulatory alternatives to be evaluated.

One particularly difficult problem facing the contractor with respect to the regulatory alternative design is the existence of numerous areas of federal pre-emption which effectively require the state to take certain actions and, for the most part, eliminate the Pollution Control Board's discretion with respect to regulatory activity. It is the Institute's viewpoint that, even though the pre-empted areas are not a matter for decision making at the state level, an assessment of the costs/benefits associated with the pre-empted areas should be made.

(B) What shall be the degree of detail in the benefit and cost components of the study?

The degree of detail of a study in each component area of the ecis may vary widely. If the regulation affects relatively few sources, then the contractor may decide to do a very detailed analysis of each pollution source in order to determine compliance behavior and control costs. An example of this would be a sulfur dioxide regulation which only affects major power plants outside metropolitan areas. Since relatively few sources are affected and each source may incur a significant control cost, the contractor is justified in making a very detailed analysis of each generating plant. Other cases exist, such as the control of hydrocarbon sources, where thousands of individual pollution control sources may be involved. In such cases, the contractor will be forced to aggregate sources into source categories and study the cost and control options available to each source category. This type of aggregation assumption can lead to situations in which a pollution control source with a certain category has been assumed to adopt a pollution control strategy or technology which, in fact, it would not be capable of using. Therefore, such aggregation assumptions will be open to question during the hearing process.

Many other areas of aggregation will also be possible within the ecis study. For example, the development of environmental quality assessments will normally require a certain amount of aggregation over time in order to characterize the environmental quality of the area surrounding a pollution control source. If the regulation is only concerned with annual average air quality, then an annual average of pollutant concentrations might be used in characterizing the environmental quality in the vicinity of, say, a large-scale power plant. If, on the other hand, a three-hour average is the time dimension used in the proposed regulation, then the aggregation to an annual average will not be acceptable. In assessing environmental quality, aggregation may also be made with respect to the geographic area surrounding the pollution control source. For certain types of pollutants, it may be necessary to model within the immediate vicinity of a pollution source; whereas other pollutants may only have citywide or countywide impacts, e.g., the geographic area associated with noise pollution vs. that associated with the creation of ozone.

The pricing behavior of firms within an industry might also have to be aggregated into larger sub-industrial groups in order to perform the ecis within acceptable budgetary constraints. The willingness to pay of some groups in the community may be different than those of other groups, say, within a different income category. The need to design a strategy to rationally compromise between the degree of detail and the amount of effort that can justifiably be spent must be made by the contractor at an early stage of the ecis design.

A number of approaches to this problem may be defined. One approach - the ideal approach - would be to aggregate sources, firms, consumer groups, geographic areas, etc. in one fashion, do the entire analysis, and then re-define the level of aggregation to determine whether the degree of detail affects the results of the ecis. This procedure, if feasible, will definitively indicate to the Pollution Control Board, that the level of disaggregation chosen was sufficient to insure that the conclusions of the study would remain valid. This procedure, however, may require a considerable amount of time and effort.

An alternative approach involves a judgment by the contractor as to which areas of estimation will come under the greatest amount of controversy or scrutiny during the Pollution Control Board hearings. These areas would then require a larger degree of disaggregation and analysis than other areas. For example, if the pollution control costs were closely scrutinized by industry but the benefit assessment was not, the contractor may be tempted to disaggregate sources in the part of the study requiring the estimation of costs but not to disaggregate with respect to the environmental quality assessment or the benefit estimation portion of the study.

A third approach would be to identify that component of the study which, because of the state of the art of analysis, will generate the largest uncertainty with respect to the accuracy of the results. Then, the accuracy of any other component of the study would not be required to be any greater than the component so identified. The solution to the aggregation design problem will not be amenable to a single guideline which will cover all cases. In part it depends upon the nature of the proposal and the objectives of the IEQ in the assessment. If the objective is to minimize error in controversial facets of the proposal, then one design will be used; if the objective is to minimize the maximum degree of error, then the relative levels of disaggregation of the different component tasks will be different. If the objective is to statistically assess the error associated with a level of aggregation, then a different strategy of aggregation and disaggregation will be called for.

(C) How will uncertainty be handled?

A number of different sources of uncertainty can be identified, each of which imparts variance to the estimates of effects of a proposed regulation. One of these is assumptions about policy parameters such as the discount rate. Such parameters are frought with some degree of uncertainty, but it is not an uncertainty that stems from randomness in the data, but rather from an uncertainty as to what exactly the correct concept should be. Another kind of uncertainty then is that related to uncertainties in prices and costs due to data errors. This would include randomness in plume models that are used to translate emissions into ambient air quality, to the per-unit costs of pieces of equipment, to the increase in prices due to increased costs that are likely to be charged, and so forth. Still another source of uncertainty is that due to technique. If, instead of using least squares regression to form a relationship between two variables, the contractor decides to use, say, some non-parametric technique to form a relationship, the results are likely to be different. Another example would be in cost estimation. If the individual decided to use the factor method of estimating costs coupled with a power rule, he would get one result; whereas, if he decided to lump everything together into a total installed cost for a plant and then use a power rule extrapolation, he would get a different result. The choice of method ideally would be related to the data and the problem at hand; but oftentimes the choice of method depends on the training and bias of the contractor and would not be necessarily related to the regulation.

It is undoubtedly difficult to state beforehand which are the items that are likely to have the greatest influence on the final evaluation for a given change in the uncertain item. If it were possible to identify the key elements, then an analysis based on most probable and a lower and higher estimate might be fruitful, but it is not clear that this should be done given the many different uncertainties.

Approaches to handling uncertainty include

- -- formal estimation of confidence intervals with quantified probability statements
- -- presentation of high, low and medium scenarios for outcome of interest such as the excess of benefits over costs
- -- tests of sensitivity of results to specified data and procedures about which there is uncertainty
- -- communication in the text in verbal terms about the data and procedure that will enable the reader to form a subjective judgment about the effects of various sources of uncertainty.

To discuss these approaches in turn, the problems of estimation, including a large number of variables entering into the results and the requirement to use judgment rather than formal statistical techniques at many points, are likely to be far too complex to permit formal estimation of confidence intervals. Thinking of approximating the logic of confidence interval estimation on a judgment basis may however be useful, giving attention to compound probabilities and the need for comparable treatment of component variables in examining the effects of different sources of variability.

High, medium and low scenarios can give a feel for the overall effects of variability though they lack rigor in the setting of values for various component variables and have not interpretation in terms of quantified probabilities. For relatively simple evaluations, where judgment rather than formal statistical estimation is predominant, this type of scenario analysis may be useful. Its usefulness is limited, however, by the fact that on the basis of the scenario results alone the reader cannot tell how the various sources of uncertainty are contributing the high and low results, and so no independent judgment about the range due to uncertainty can be formed.

Of all the ways of handling uncertainty, sensitivity tests to specified changes in data and procedures have the most to recommend them. The reader can relate cause of change in estimate to the reason for the change and can form his own judgment as to the likelihood that the change will occur. Some sensitivity tests can be reported in fair detail in the text of an ecis. Given that there should be many sensitivity tests, a procedure other than for sensitivity tests found to be of particular key importance is to report verbally in a brief way on the outcome of a number of sensitivity tests, so that the reader will know they were carried out and will know the bottom line on the sensitivity results without being overwhelmed by a barrage of numbers pertaining to sensitivity.

Even with the greatest attention to conducting sensitivity tests, there are more variables than can be tested, particularly when one considers that various component variables can be varied either independently or jointly. The final method for handling uncertainty will therefore almost certainly have a place in most ecises. That is, there will be a discussion of factors affecting the reliability of estimates with appropriate strong points and caveats brought out verbally in such a way that the reader can get a feel for the uncertainty without actual numerical comparisons.

(D) What is the best disciplinary mix?

As remarks throughout this chapter have brought out, the disciplinary mix should emerge from the needs of the study. If the contractor does not feel he can hire on a consulting or subcontractor basis any needed disciplinary competence which he does not have, he should not undertake the study. If it is possible to draw on previous ecises for some particular parts of the analysis, the need for hiring the disciplinary competences in these parts will be obviated. Besides expense, problems of coordination and communications between persons of different disciplines may act to hold down the number of different disciplines actively used in the analysis.

How to Use This Handbook

A suggested first stage in designing an ecis is to sketch an outline of the possible parts of the study, adapting the format of Figure 1 to the regulation to be evaluated. For each part of the study, two or three different methods of approach should be noted raning from the less to the more sophisticated. One of the uses of the remaining chapters of this Handbook is to help in identifying the possible approaches.

Next a wide judgmental range could be assigned to the outcome of each part of the study, based on very preliminary assembling of data throwing light on the likely outcomes. One will thus have carried out a very crude approximation for each of the steps of the study and can form judgments on how to deal with the design issues considered in this chapter.

The design can then be finalized, including final choice of techniques and scoping out of detailed work plan, again drawing on the remaining chapters of this Handbook. Among the remaining chapters, Chapter Three describes techniques available for environmental modelling which is the middle box in the upper part of Figure 1. Chapter Four pertains to the right upper box and is on benefit estimation. Chapter Five on cost estimation pertains to the first part of the lower box of the figure. Finally, Chapter Six describes various methods for estimating the economic incidence effects which are also listed in the lower box.

CHAPTER THREE: ENVIRONMENTAL QUALITY ANALYSIS

Ambient environmental quality is the primary connecting link between pollution policy and environmental damages. In very few instances can a transition from a regulatory action pertaining to discharge concentrations be made directly to benefits assessment. Environmental quality analysis should ideally be performed for each identified policy alternative or regulatory scenario. Data availability, methodological deficiencies, and other constraints will very likely limit the extent to which such analysis may proceed. The ecis contractor is therefore faced with the question of deciding what method of assessment is both feasible and warranted.

This Chapter presents material regarding the use of mathematical and computer simulation models for environmental quality analysis. As such is in primarily a restatement of the material contained in Appendix F of Roberts and Sievering, 1977. The two major areas addressed are air and water quality assessments. Following the presentation of modeling considerations is a step-by-step procedure for environmental analysis for each area (adopted from Canter, 1977). References to sources giving more detailed instructions regarding the use of environmental models are included. In addition to the material presented here a number of other factors pertaining to environmental quality analysis should be considered. For this reason the reader is urged to review Chapter Three of Roberts and Sievering, 1977 along with this section of the Handbook.

Rollback Modeling. The simplest air pollution model is the rollback or proportional model. It is a linear model in that it assumes changes in emissions are proportionally related to ambient concentrations. No other air pollution model was used until the late 1950's. As air pollution worsened, the rollback model was given a quantitative basis in order to make it more useful.

In its simplest form, rollback assumes that the concentration of any long-lived pollutant at any given point is equal to a background concentration plus some linear function of the total emission rate of that pollutant in the area which influences the concentration at that point.

$$C_p = a + bE$$

where C_p is the ambient concentration of one pollutant at point p (expressed in ug/m^3); a is the background concentration of that pollutant for air uninfluenced by those nearby emitters which influence the concentration at point p (expressed in ug/m^3); b is a proportionality factor which takes into account the meteorology, location of all emitters as seen from point p, and other factors which influence the source-receptor interaction at that point (expressed in $\frac{ug\text{-}sec}{g\text{-}m^3}$); and E is the total emission rate of all emitters of that pollutant within the geographical area modeled, normally a city or metropolitan area (expressed in g/sec). (Fig.1)

For standard-setting purposes, one proceeds by solving for E to define the allowable emission rate.

$$E_A = (C_A - a) / b$$

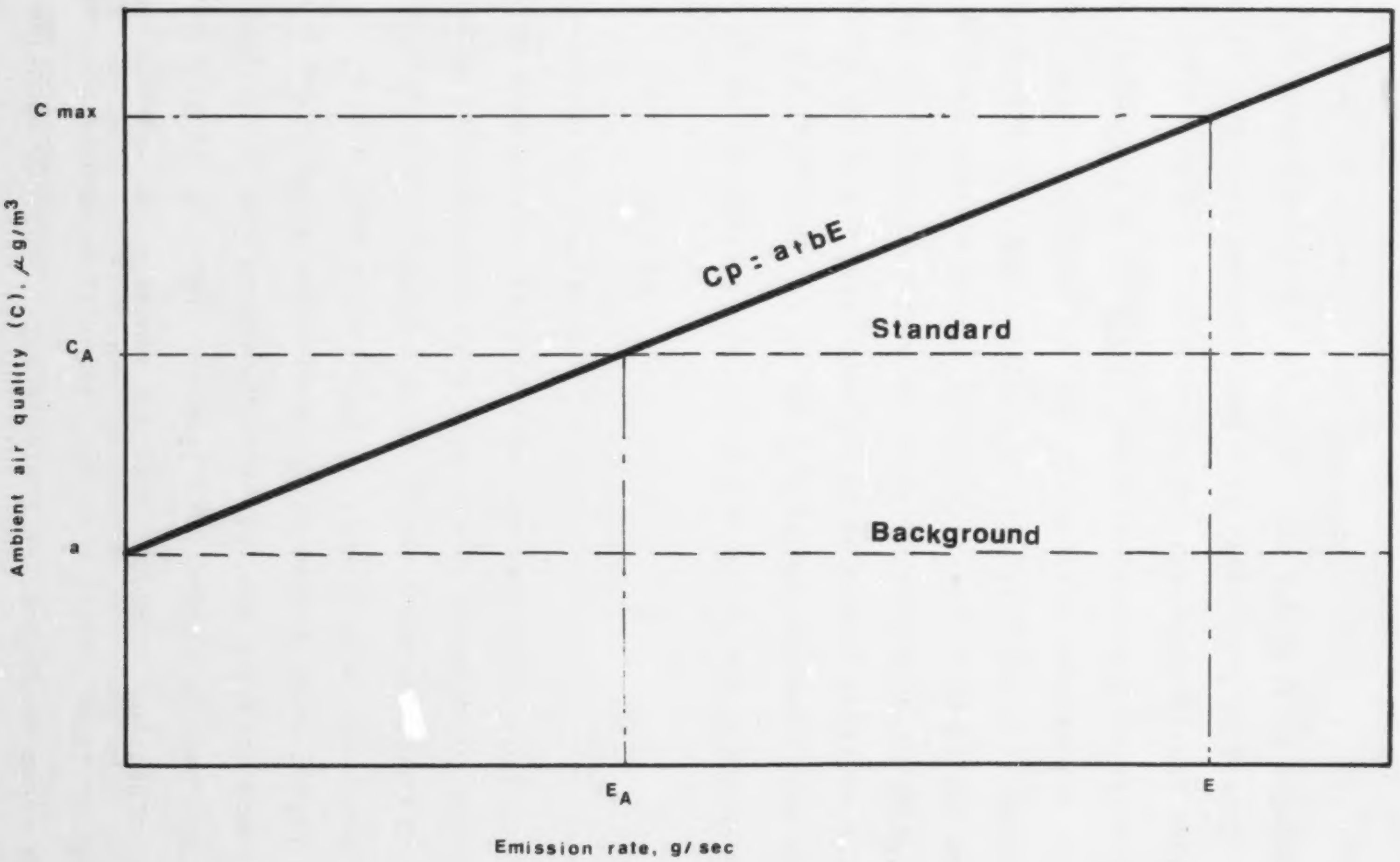


Figure 1. Graphical Relationships in Rollback Modeling

where the subscript A indicates the rate which produces the allowable concentration at the particular point of interest. One then assumes C_A to be ambient air quality standard for the pollutant of interest. The value of b is not constant for a given city, but rather is a function of location within the city. It would be higher near an emitter and lower away from major emission sources.

In order to meet air quality standards, it is necessary for the concentration at all points to be at or below the particular standard. Therefore, the value of b which corresponds to the highest value of C is determined for this value.

$$B = (C_{max} - a) / E$$

Here C_{max} is the highest pollutant concentration in the region of interest. By substituting this value for b, we obtain

$$E_A = E(C_A - a) / (C_{max} - a).$$

Further analysis and use of rollback modeling is described in deNevers and Morris (1975).

Limitations of Rollback Modeling. The rollback model is widely used because it is simple and requires little data. However, it has three major limitations:

1. The rollback model has no experimental verification because the relationship between the concentration and emission rate assumes that all other factors remain unchanged, including the spatial distribution of emissions. Therefore, to test the equation, one would have to reduce the emission of each and every emission source in the area by the same percentage.

2. The application of rollback modeling requires knowledge of the value of C_{max}, the highest concentration of the pollutant in an area. In general usage, one substitutes the highest observed concentration $(C_{max})_{obs}$ for C_{max}. These will only be equal if an air quality measuring station is in fact located at the point of maximum concentration.

3. Rollback modeling is applicable to the problem of determining the effect on air quality of a change in emission rate of one emitter or one class of emitters, without equal percentage changes in the emission rates of the other classes of emitters, only if one of the following three situations exists:

a. The class being considered is by far the largest contributor to the pollutant in question, so that we can ignore the effects of others or ignore the inaccuracy of making the assumption that their contribution at the worst point has the same factor of proportionality as the group of sources we are considering.

b. The class being considered has the same temporal, spatial, and vertical distribution of emissions as the average of all other emissions in the area being modeled, so that a change in its emission rate has the same effect on emission distribution in time and space as a properly-scaled reduction in all emission rates would have.

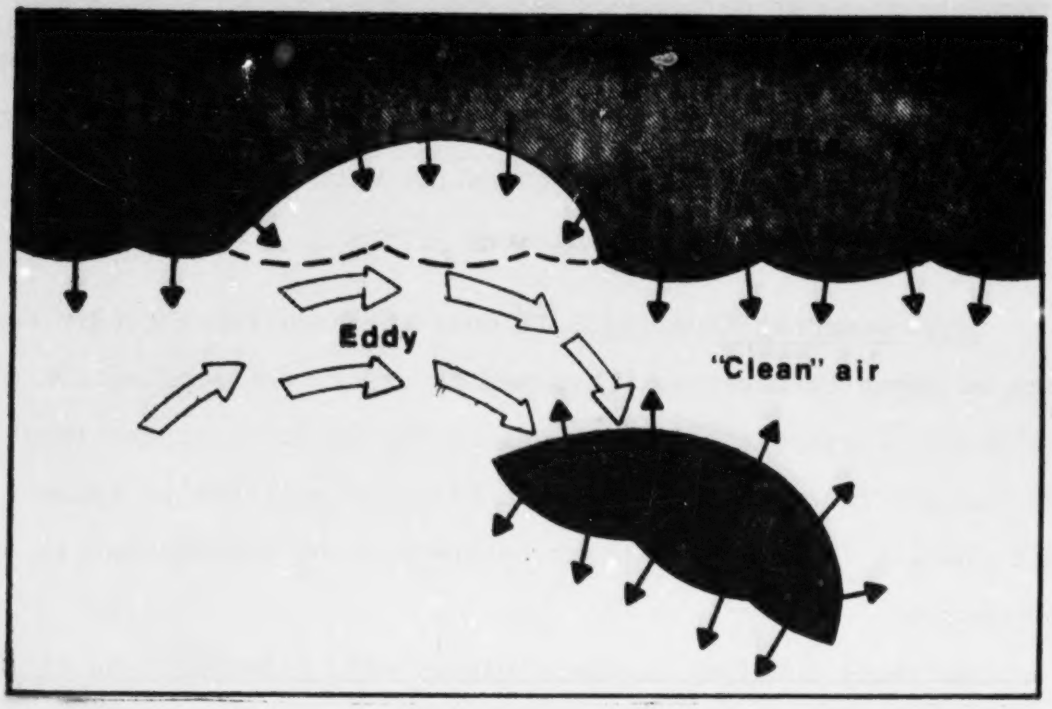
c. The standard for this pollutant is a short-term standard which is most severely tested in periods of excellent mixing within a limited unchanging air volume, as might occur in a well-mixed layer under an inversion in a completely closed valley with no exchange of air with the surrounding area.

Environmental Modeling. If none of these three conditions can be shown or reasonably assumed to exist, the application of rollback or proportional modeling to the question of the impact of changes in the emission of one class of emitters on ambient air quality is totally without theoretical or experiemental foundation.

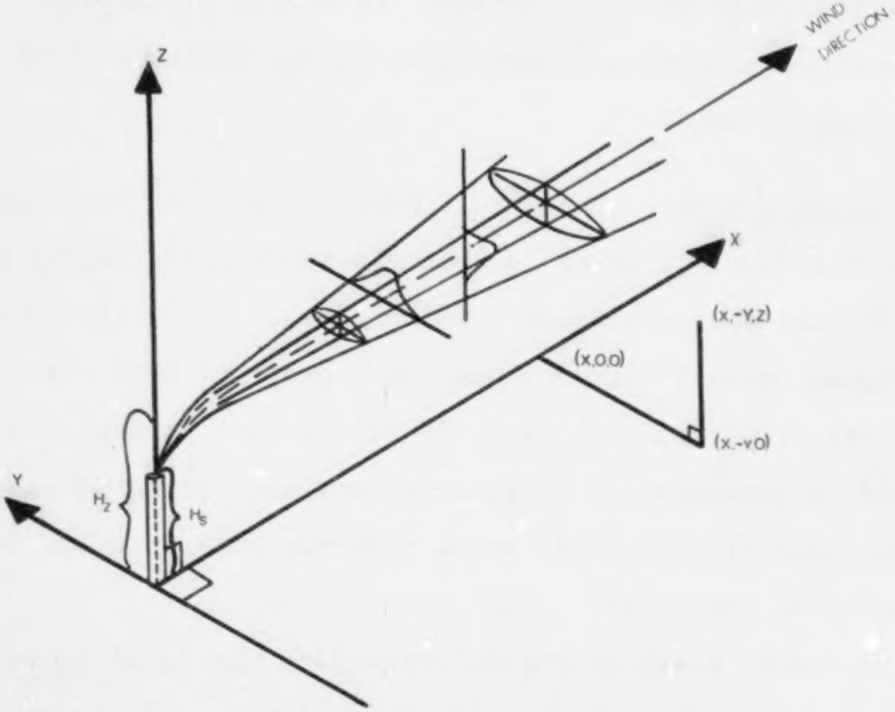
Rollback modeling has been widely used because it is simple and understandable. As stated above, it is a model with limited experimental verification. For those situations where its theoretical base is inappropriate, it should not be used; more accurate models such as those based on the Gaussian plume equations must be used.

Gaussian Model. The actual physical process that transports pollutants from one point in space to another is largely a combination of wind and turbulence. Turbulence is the collective random (or almost random) motion involving a group of many distinct particles or molecules. (Fig. 2) It is this process that is assumed to generate the cross wind transport of pollutants, while average wind direction and speed together consitute the downwind component of transport. (Fig. 3)

With this basic assumption regarding the driving mechanism for the spatial distribution of any pollutant, the Gaussian plume formulation can be derived.



(Figure 2. Grossly simplified view of how a turbulent eddy breaks up a plume and causes much more rapid mixing of pollutants with ambient "clean air" (Williamson, 1973).



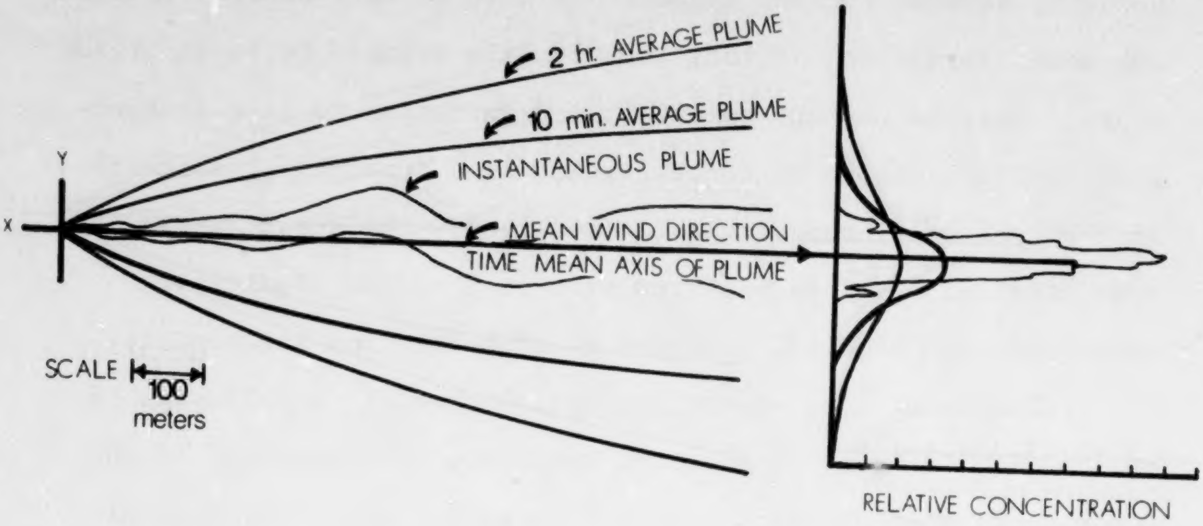
(Figure 3. Coordinate system showing gaussian distributions in the horizontal and vertical (Perkins, 1974).

However, several further assumptions must be made before beginning the model formation. First, the plume is assumed to be in steady state. This means that pollutant concentration is time independent, and any change in concentration is a function of distance in the horizontal and vertical dimensions. The steady state approximation also assumes wind velocity, eddy diffusivity, emissions, and chemical reaction rates to be time independent.

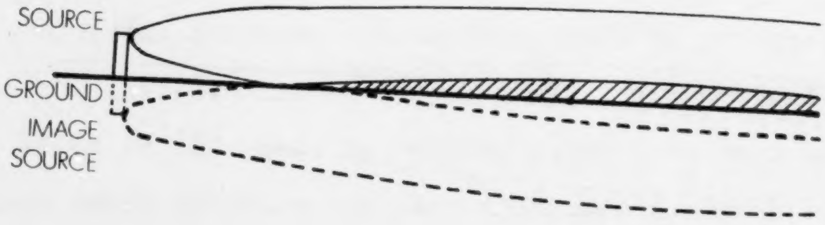
This leads to a second assumption that, if a pollutant is emitted from a point source, the resulting concentration in the atmosphere, when averaged over sufficiently long time, approximates a normal statistical distribution in space. This distribution is measured cross-plume and is considered normally distributed in both the horizontal and vertical dimensions. (Fig. 4)

A third assumption is that no chemical reactions take place in the plume to increase or decrease the pollutant concentration of concern. Fourth, the Gaussian model requires a point source of pollution. Fifth, meteorological conditions are considered to be constant for the entire period of analysis. Sixth, the pollutant is either perfectly reflected from or totally absorbed by the surface, no matter what its condition. (Fig. 5)

Every one of these assumptions prevents complete accuracy of the final result. Winds do not remain constant and in the same direction even over short periods of time. It is to be expected that some chemical reactions take place in the plume since the pollutants are "hot", and the ambient air contains many reactive compounds. The problem with letting emissions remain constant is that in many industrial processes there are breaks in the production process which may cause a marked change in the emission rate.



(Figure 4. The diagram on the left represents approximate outlines of a smoke plume observed instantaneously and of plumes averaged over 10 min. and 2 hr. The diagram on the right shows corresponding cross-plume distribution patterns (Slade, 1968, from Perkins, 1974).



(Figure 5. Source and image source below ground used to calculate the concentration owing to a plume. In the shaded region, the pollution is increased by the amount corresponding to the image source (Perkins, 1974).

By allowing emissions to remain constant, a model may presume a higher level of emitted pollutants with the resultant calculation giving too-large values. There are formulations of the Gaussian model that assume continuous emission line and area sources, but most formulations assume a point source. Multiple sources ban be summed; however, this is not extremely accurate and introduces uncertainty in the results.

Given all these assumptions, it is obvious that any results obtained from this process must be considered only as estimates of what is actually happening "out there".

The actual model is designed to be used with a coordinate system. (Fig. 3) The height of the source is H_s, and the effective height of the plume due to plume rise is H_e. Figure 5 depicts the assumption of perfect reflection. This is handled mathematically by assuming an identical source below the ground with the shaded area being that portion of plume added to the original concentration. The basic solution for the situation portrayed in Figures 3 through 5 is

$$C(x,y,z,H) = \frac{Q}{\pi \bar{u} \sigma_y \sigma_z} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2 + \left(\frac{H}{\sigma_z}\right)^2 \right]$$

where C = concentration of pollutant at some point (x,y,z) in g/m^3

Q = emission rate in g/sec

$\bar{u}$ = mean wind speed in m/sec

σ_y = y direction dispersion coefficient in meters

σ_z = z direction dispersion coefficient in meters

H = effective height of source in meters

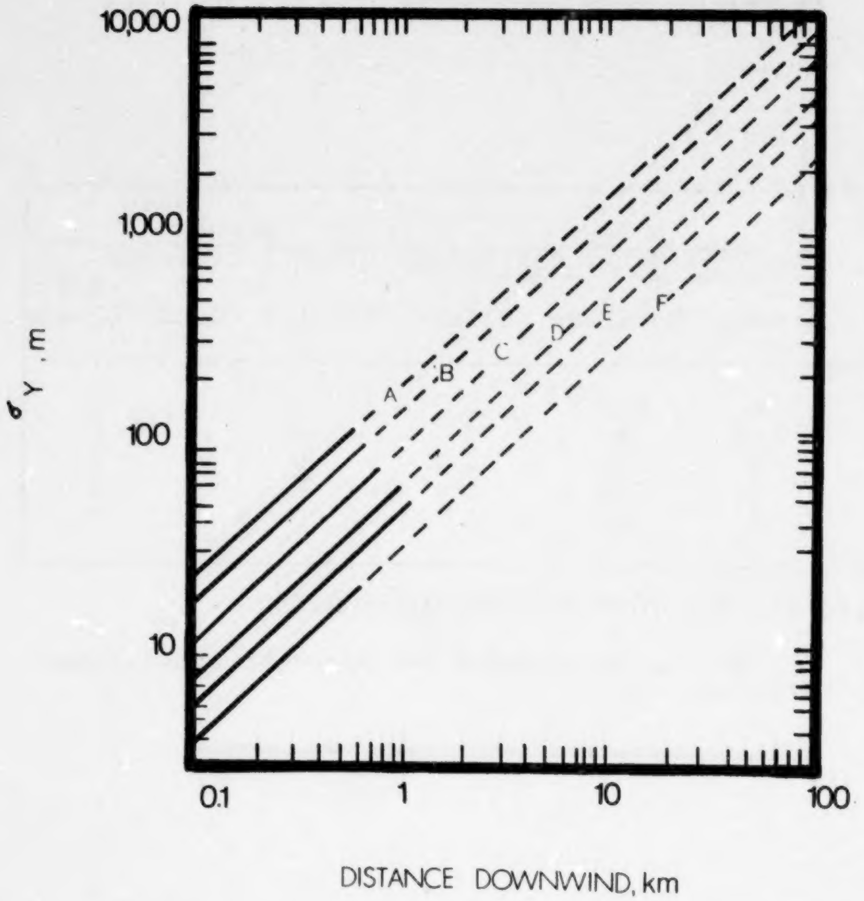
Values for σ_y and σ_z, indicators of the turbulence generated cross-wind pollutant transport, must be determined by comparison with observational data. A common reference for determining these coefficients is Workbook of Atmospheric Dispersion Estimates (Turner, 1970).

Both σ_y and σ_z are primarily functions of the turbulent structure of the atmosphere, but are also functions of the surface roughness, sampling time, wind speed, and downwind distance from the source. Turner uses a sampling time of 10 minutes in deriving his estimates. The source height is assumed to be the lowest several hundred meters of the atmosphere with a surface of relatively open country. It should be noted here that most pollutant calculations actually performed are not for open country but rather are for urban areas with the modeled concentration being only approximations of the actual concentrations. The turbulent structure of the atmosphere is parameterized by Turner-given values for incoming solar radiation and overcast sky. In Table 1 Turner uses stability categories designed for use with the Gaussian model. "Strong" solar radiation corresponds to a solar altitude in excess of 60° with clear skies; "slight" insolation corresponds to a solar altitude from 15-30° with clear skies. Cloudiness will obviously decrease the amount of incoming solar radiation. Incoming radiation is reduced to moderate with broken (5/8 to 7/8 cloud cover) clouds and slight with broken low clouds.

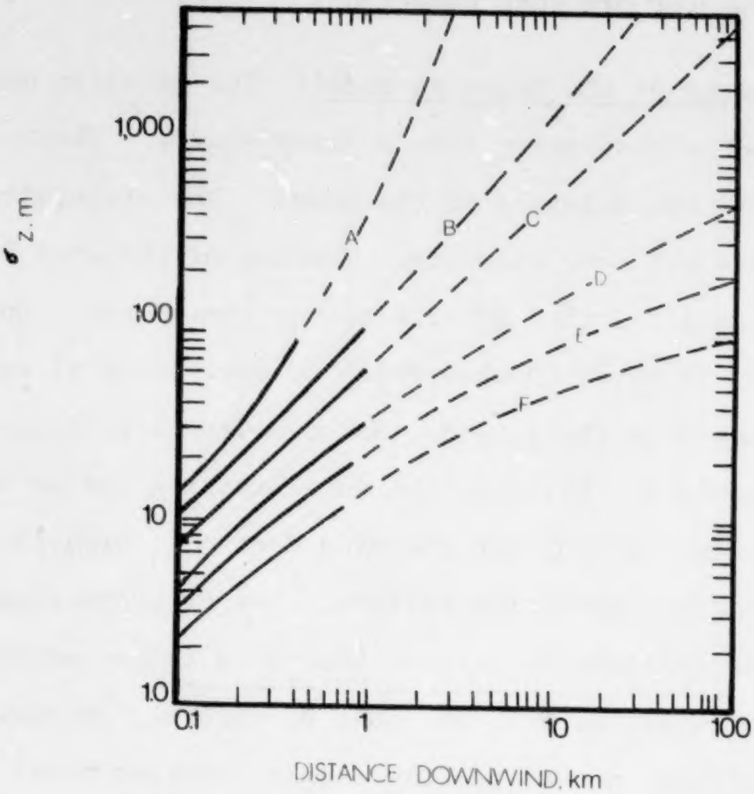
Surface Wind Speed (at 10 m), m sec^{-1}	Day			Night	
	Incoming Solar Radiation				
	Strong	Moderate	Slight	Thinly Overcast or -4/8 Low Cloud	-3/8 Cloud
2	A	A-B	B		
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
6	C	D	D	D	D

Table 1. KEY TO STABILITY CATEGORIES

The Neutral class, D., should be assumed for overcast conditions during day or night (Turner, 1970).



(Figure 6. Horizontal dispersion coefficient σ_y as a function of downwind distance from the source (Turner, 1970).



(Figure 7. Vertical dispersion coefficient σ_z as a function of downwind distance from the source (Turner, 1970).

Figures 6 and 7 portray the magnitudes of horizontal (σ_y) and vertical (σ_z) dispersion coefficients respectively as a function of stability classes. With these graphs it is possible to estimate σ_y and σ_z for use with Equation 1.

Limitations of the Gaussian Model. The Gaussian model allows an estimation of dispersion from a fixed source. There are many limitations to the accuracy of the model. The dispersion coefficients are not very accurate. Turning of the wind with height owing to surface friction effects is not considered. Only partial consideration is given to absorption or deposition of pollutants when the plume hits the ground. No consideration is given to chemical reactions. There is the very limiting use of mean winds for the sampling period, for the wind does not normally remain constant even for short time periods. Use of short-time average diffusion coefficients to predict hourly or longer average concentration also causes error. One must be careful, in view of all these limitations, not to use the simple Gaussian model for more than first estimates of pollutant concentration.

There have been several critical reviews of the Workbook of Atmospheric Dispersion Estimates. According to Fulle (1976), there is poor agreement between the Workbook method for determining stability classes and two further methods recently developed. The degree of agreement between the three methods did not vary appreciably with location and exhibited stronger variations with time of day. According to Portelli (1976), the neutral class is over-predicted by the Workbook, and stable classes are under-predicted.

With these considerations in mind, it must be stressed that any results obtained from use of Turner stability classes will not be highly accurate. Thus, it is often more meaningful simply to calculate the maximum ground level concentration and its location. The Gaussian formulation for neutral conditions gives the maximum concentration C_{max} as

$$C_{max}(x,y,z,H) = \frac{3Q}{4\pi \bar{u} H^2}\left(\frac{\sigma_z}{\sigma_y}\right)$$

occurring at $x = \frac{1}{16}\left(\frac{H}{\sigma_z{}^2}\right)^4$.

Computer Models Available Using the Gaussian Plume Equations

The majority of computer-based simulation models utilize the Gaussian plume equations. There are many such simulations available for use in modeling air pollutants in different situations. Presented below are those which have received wide usage and are available through various public and private agencies.

User's Network for Applied Models of Air Pollution (UNAMAP)

This is a set of air pollution models developed by the Environmental Protection Agency. UNAMAP is available to EPA Regional Offices, as well as to users with their own computers. The UNAMAP series may be purchased from the National Technical Information Service (NTIS).

There are six different models in the series which will be described briefly in the following sections. A user's manual is available for the entire series which will further acquaint potential users with the capabilities and limitations of each model (Khanna, 1976).

1. APRAC-1A (Urban Diffusion Model Computer Program). The APRAC-1A diffusion model has been developed as a versatile and practical model for computing the concentrations of pollutants at any point within a city. The model calculates the pollutant contributions from diffusion on various scales, including: a) extra-urban diffusion, mainly from sources in upwind cities, b) intra-urban diffusion from freeway, arterial, and feeder street sources, and c) local diffusion of emissions within a street canyon. Currently the model treats only carbon monoxide (CO), a relatively inert gas in the atmosphere, but an important pollutant in terms of health.

A detailed description of the model is given in the "User's Manual for the APRAC-1A Urban Diffusion Model Computer Program" (Mancuso, 1972). The computer program of the model can be used to make calculations of the following types:

a) Synoptic model: Hourly concentrations as a function of time, for comparison and verification with observed concentration and for operational applications.

b) Climatological model: The frequency distribution of concentrations, for statistical prediction of the frequency of occurrence of specified high concentrations in connection with planning activities.

c) Grid-point model: Concentrations at various locations in a geographical grid, providing detailed horizontal concentration patterns for operational or planning purposes.

The US EPA has recently developed the APRAC-2A modeling programs. Further information on this will be incorporated in later revisions of this Handbook. In the meantime interested contractors should contact the US EPA directly.

2. Climatological Dispersion Model (CDM). The Climatological Dispersion Model (CDM) calculates long-term (annual or seasonal) concentrations for quasi-stable pollutants at an array of ground-level receptors. Two non-reactive pollutants can be modeled simultaneously. The model can deal with a maximum of 200 point sources and 2,500 area sources, with the minimum grid square of the latter being 1 km on a side. Calculations can be determined for a limit of 200 receptors with no restrictions on their locations. Average emission rates from point and area sources along with the joint frequency distribution of wind direction, wind speed, and stability for the same period are the basic input to the model.

This model has replaced an earlier model for determining long-term concentrations for non-reactive pollutants. The replaced model (Air Quality Display Model (AQDM)) differed from the newer CDM in three ways: method of calculation for area sources, application of Brigg's plume rise formulae, and introduction of a power law increase in wind speed with height as a function of atmospheric stability. A complete description of CDM is available in the "User's Guide for the Climatological Dispersion Model" (Busse and Zimmerman, 1973).

3. Point/Maximum (PTMAX). This program is used to determine both the maximum concentration and the distance to maximum concentration for a point emission source. The concentrations calculated by the program are for the single emission source considered; where multiple stacks exist at a given plant, this program can be applied individually to each stack.

However, the program does not compute the maximum concentration for the combination of the stacks at the plant. This program is useful for determining the combination of wind speed and stability which produce maximum concentration. Also, the critical wind speed, i.e., the wind speed that causes the maximum concentration, can be determined for a given atmospheric stability class. This program is available in an interactive, computer terminal mode and is easy to use.

4. Point/Distance (PTDIS). This model determines the concentration at ground level from a single point source. This program is useful in examining the variation of ground-level concentration with distance. It is also available in an interactive computer terminal mode and is quite easy to use.

5. Point/Multiple Point (PTMTP). This program predicts hourly concentrations at up to 30 specified receptor locations resulting from emissions of up to 25 point sources. It too is interactive easy-to-use program.

It should be noted that all of these programs assume a number of basic conditions that prevent them from being directly applicable to many specific problems. These assumptions are those brought forth in the discussion of the Gaussian plume equations. While all of these models can be applied to urban situations, the results must be viewed in light of the limitations of the basic equations.

6. Highway Air Pollution Model (HIWAY). The HIWAY model computes air quality levels downwind from non-reactive pollutants

in relatively uncomplicated terrain for distance ranging between tens of meters to hundreds of meters.

In determining estimates of concentration values for an "at-grade" highway, motor vehicle traffic emissions are considered to be equivalent to a series of line sources. Each lane of traffic is modeled as though it were a straight, continuous, finite line source with a uniform emissions rate. Air pollution concentrations downwind from a line source are found by a numerical integration along the line source of a simple Gaussian plume model. An estimate may also be made of air pollution concentrations downwind of a depressed highway or cut section. For this configuration, the top of the cut section is considered to be equivalent to an area source. This area source is simulated by using a series of ten equal line sources such that the total source strength is equal to the total emission of the highway. A complete description of this model is available in the "User's Guide for HIWAY" (Zimmerman and Thompson, 1975).

It should be noted that this model has been improved by Argonne National Laboratory, Energy and Environmental Systems Division. The difference between ANL/HIWAY and the EPA/HIWAY models lies in their usefulness for conducting policy evaluations or preparing environmental impact statements. A complete description of ANL/HIWAY is available in "ANL/HIWAY: An Air Pollution Evaluation Model for Roadways" (Concaildi, et al.,1976).

Other Air Quality Models.

Particle in Cell (PIC) Models.

"Mathematical Modeling of Photochemical Smog using the PICK Method" by R.C. Sklarew. Journal of Air Pollution Control Association 22, 1972, p. 865.

PICK is based on the use of Lagrangian mass points and is one of a group of particle in cell techniques. Changes in a pollutant particle are calculated to simulate pollutant mass transport due to both advection and diffusion. This model requires computer time and a moderate amount of data to run.

One Box Models.

"A Simple Dispersion Model for the Analysis of Chemically Reactive Pollutants", by Steven Hanna. Atmospheric Environment, 7, 1973, p. 803.

This dispersion model assumes that the surface concentration of a chemically reactive pollutant is proportional to the local area source strength and inversely proportional to the average width of the region being considered divided by the average depth within a region. It is used with point sources at ground level. Some computer capability is required, but the data requirements are not extensive.

Eularian Multiple Box Models.

"Multiple Box Model for Dispersion of an Air Pollutant from Area Sources," by Kenneth Ragland. Atmospheric Environment, 7, 1973 p. 1017.

These models feature two dimensional diffusion for computation of the ambient air concentration of a pollutant emitted from an area source. It is simple and inexpensive to run on a computer. This models a fair amount of meteorological data and basic emission data.

Lagrangian Box Models.

"User's Guide to Diffusion Kinetic Code (DIFKIN)", by J.R. Martinez. Final Report EPA Contract #68-02-0336 by General Research Corp.

Lagrangian box or trajectory model simulates time history of pollutant concentration within boxlike elements of constant volume as they flow along wind streamlines between terrain heights and inversion base height. It can handle chemically reactive pollutants. This model is data intensive and requires a large amount of computer time.

Air Quality Procedural Description. The basic steps associated with prediction of changes in air quality are:

1. Describe or determine the existing air quality levels in the area. If possible, present historical trends in air quality. Examine the frequency distribution and the median and mean concentrations for the pollutant being studied.

2. Determine the air pollution dispersion potential for the area; this can be accomplished by aggregating information on seasonal or monthly variations of mean mixing depth, inversion heights, wind speeds, high air pollution potential, and episode-days. Describe historical records of air pollution episodes in the area.

3. Summarize the basic meteorological data for the area; this would include monthly summaries of precipitation, temperature, wind speed and direction, solar radiation, and other parameters if deemed appropriate. Include in this information the monthly, seasonal, and annual wind roses. Identify meteorological phenomena that have occurred in the area.

4. Relate ambient air quality and emission standards to existing air quality.

5. Summarize emission inventory data for the smallest applicable scale of the region and include the regional emission inventory.

Identify the major point sources of air pollution in the area and indicate the quantities of pollutants emitted as well as the location of these point sources.

6. Determine the mesoscale impact due to each alternative. This can be accomplished by calculating the estimated annual quantity of air pollutants from each alternative and determining the percentage increase in the regional and local emission inventory for each pollutant emitted.

7. Calculate the ground level concentrations of air pollutants from the alternatives under varied meteorological conditions. Develop isopleths of concentration in the vicinity of the sources of emissions.

Water Quality Models. Pollution discharges to water systems consist of two basic classes of substances. Those which do not decay with time or leave the system by settling, adsorption, chemical reaction, or other means are termed conservative. Included in this group are total dissolved solids, chlorides, and other species which can be assumed as non-reactant. Species which decay very slowly such as organo-chlorine biocides may also be considered conservative for water modeling purposes. Substances which exhibit quicker time decay and reactant properties are termed non-conservative. Examples include biochemical oxygen demanding (BOD) materials such as sewage and paper pulp and radioactive materials. The rate of decay or removal is usually assumed to be proportional to the amount present at any time, t. This assumption is referred to as first order reaction kinetics.

Mass Balance in Aquatic Systems. Most water quality models pertain to river or stream systems. The key property used in formulating the general model assumes a mass balance relationship.

A further assumption is that the concentration of water quality variables only varies in the direction of streamflow. There is no variation with depth or width. The coordinate system used is shown in Figure 8. The downstream direction of flow is labeled the "X" direction.

The last crucial assumption relates to plug flow, i.e., that the water doesn't subject the material to mixing due to diffusion or dispersion. Figure 9 illustrates ideal plug flow and the profile usually encountered in practice.

By considering the conditions for mass balance to exist for a particular volume of water in the plug, the following general form of the differential equation for a non-dispersive, single pollutant system is used:

$$\frac{\partial s}{\partial t} = -\frac{1}{A}\frac{\partial (Qs)}{\partial x} \pm Ks + s\frac{\partial Q}{\partial x}/A \pm S_d$$

where s = concentration of the pollutant at any time, t (e.g., in mg/l, ppm, etc.)

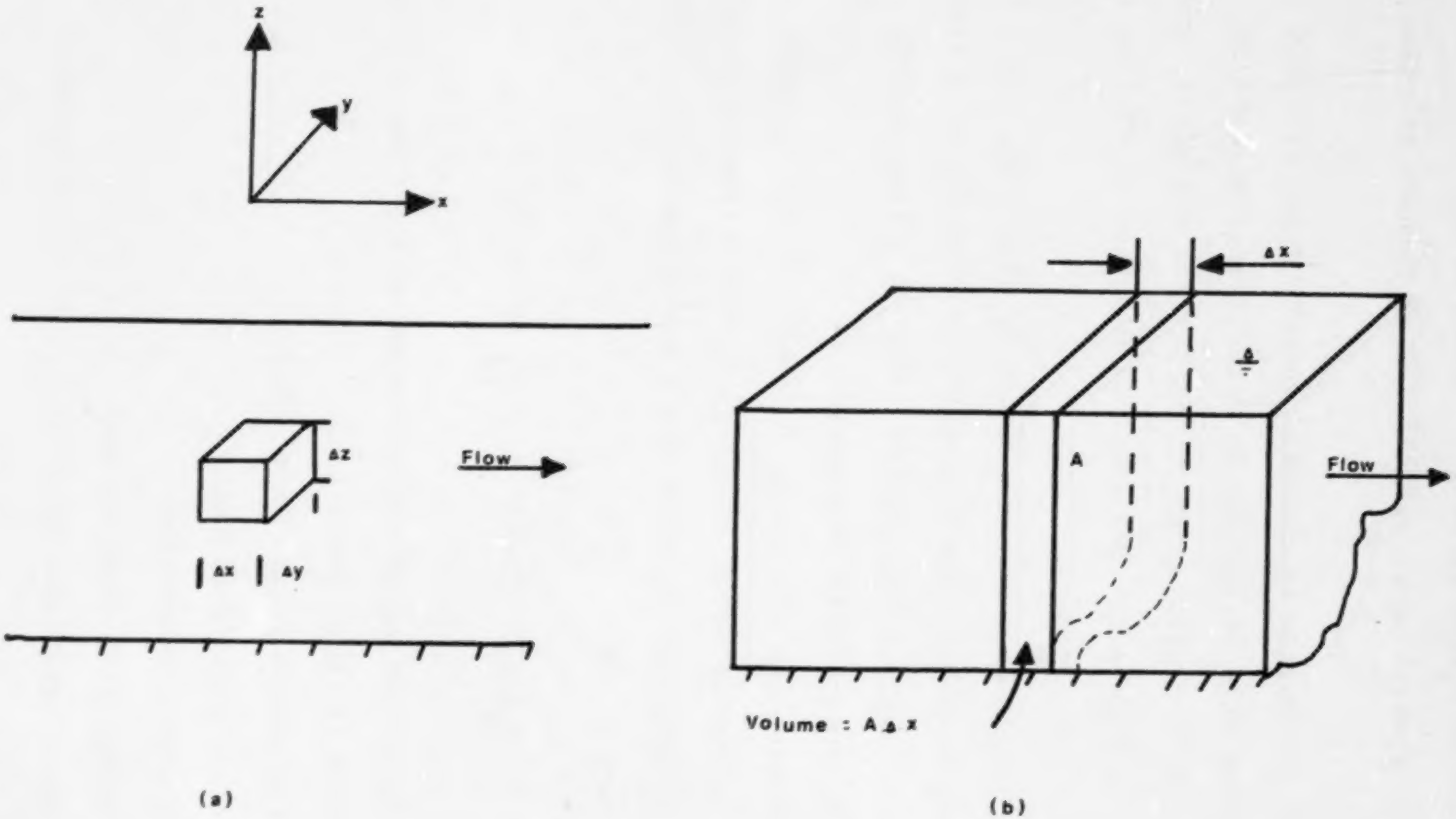
Q = streamflow (e.g., in m^3/sec)

A = cross-sectional area

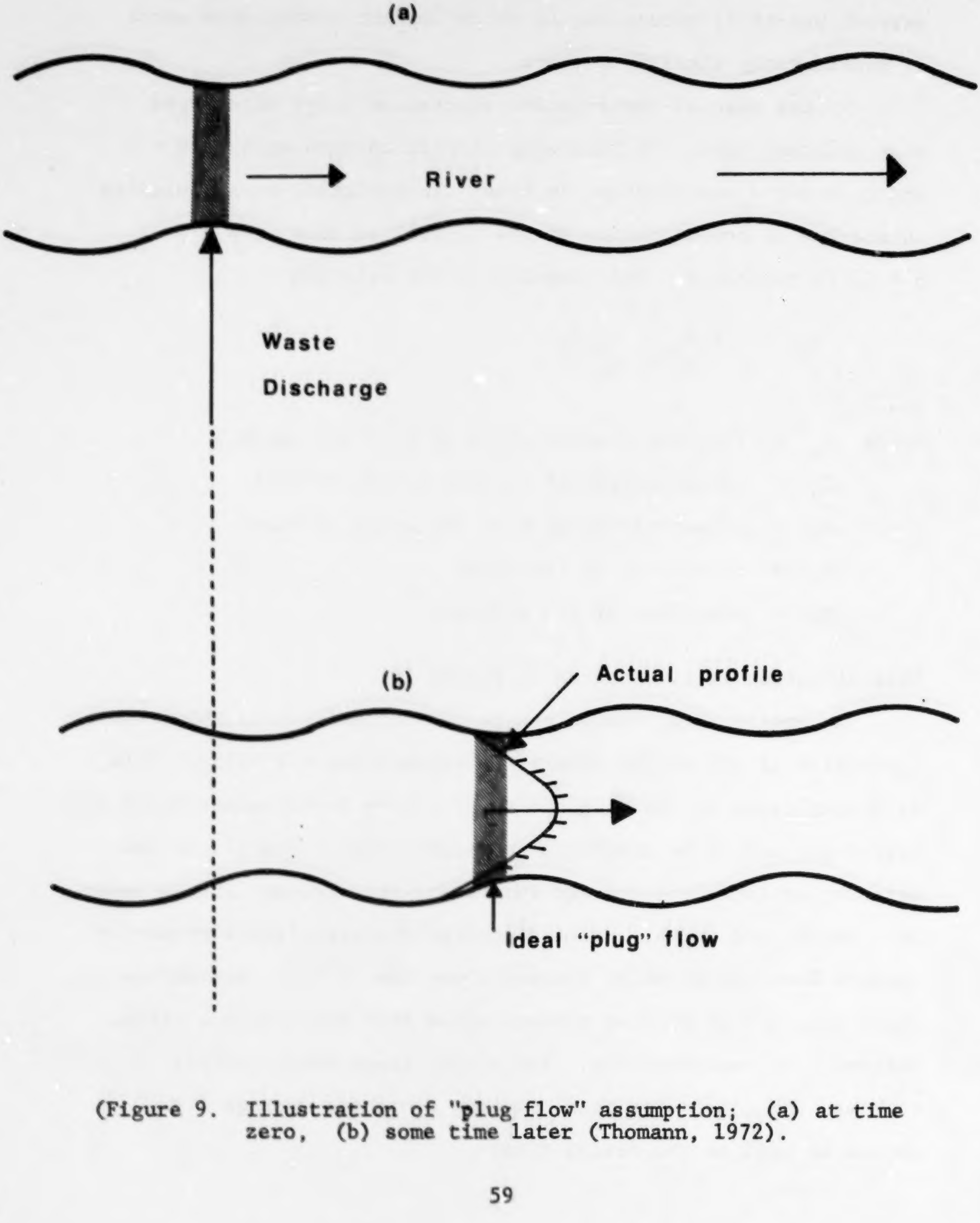
x = distance downstream

K = first order reaction rate

S_d = distributed sources or sinks of the pollutant.



(Figure 8. (a) Infinitesimal volume in rivers, (b) elemental "slice" of river (Thomann, 1972).



(Figure 9. Illustration of "plug flow" assumption; (a) at time zero, (b) some time later (Thomann, 1972).

Although this equation may appear formidable, there are several practical situations in which further assumptions serve to considerably simplify matters.

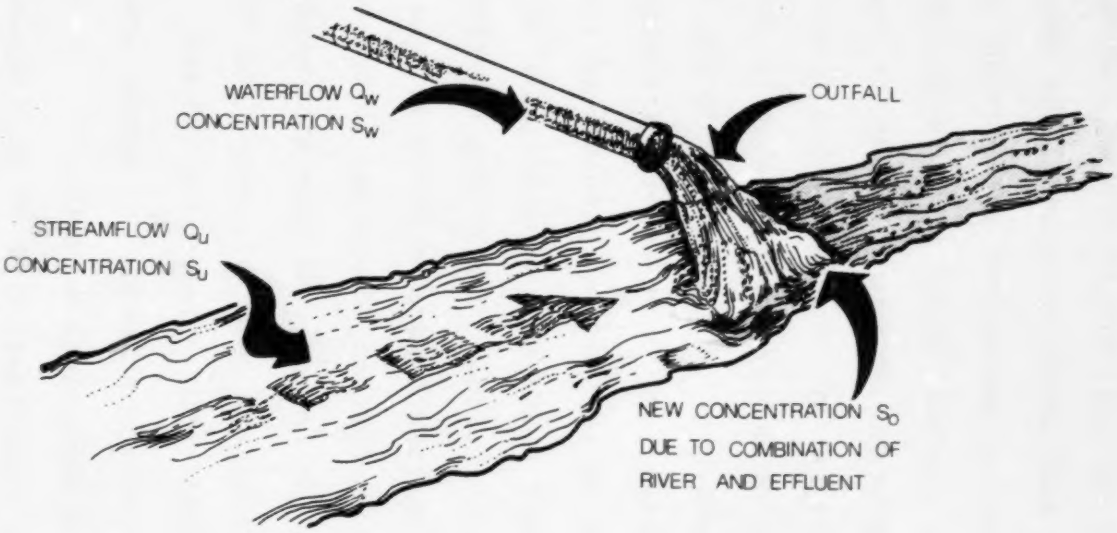
In the case of conservative substances being discharged at a constant rate, the following simplifications apply: $K = 0$ and Q, A and s are constant in time. In addition, we are usually interested in concentration at the outfall so that at $X = 0$, $S = S_o$ (a constant). This results in the relation

$$S_o = \frac{S_u Q_u + S_w Q_w}{Q_u + Q_w}$$

where S_o = instream concentration of S at the outfall
S_u = concentration of S prior to the outfall
S_w = concentration of S in the waste effluent
Q_u = streamflow in the river
Q_w = wasteflow of the effluent.

This situation is illustrated in Figure 10.

An entire river system can be modeled using only this simple expression if all of the underlying assumptions are valid. This is accomplished by dividing the river system into reaches based upon hydrologic and waste discharge characteristics. Hydrologic characteristics include: average runoff and flow values, stream velocity, depth, and width. Waste discharge characteristics primarily concern location of point sources along the system. Streamflow rates used are of special concern since they exert such a strong influence on concentration. For steady state water quality studies, the one in ten year, minimum seven day average flow should be used as the design flow.



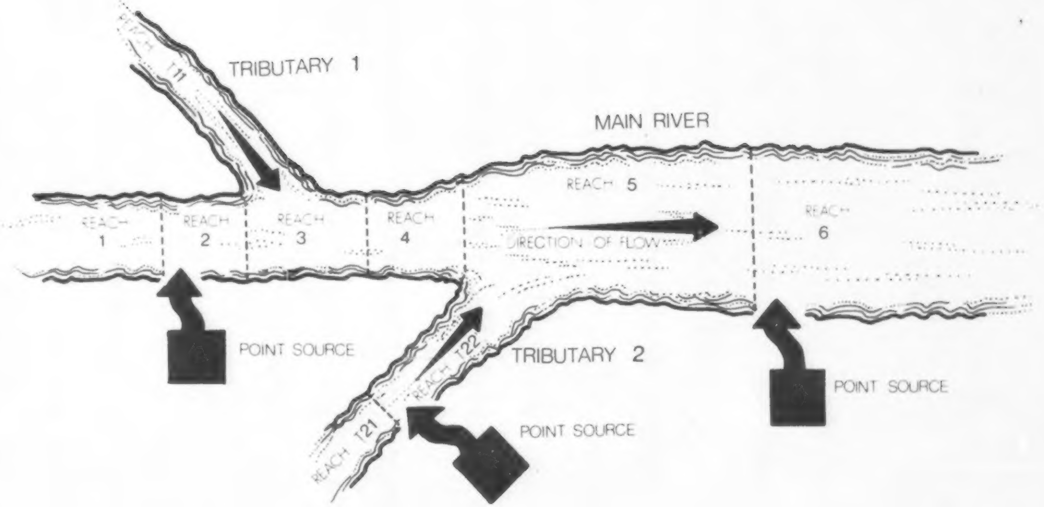
(Figure 10. Pictorial View of Single point source, conservative, Steady-state water quality relations (Equation F-8).

Figure 11 depicts a small system divided into nine reaches. It consists of a main branch with two tributaries and three pollution point sources. Each reach marker (indicated by the dashed line) was established at a point where a potential change in concentration is possible due to either a change in flowrate or introduction of additional pollutant. The concentration in each reach can be found by successive applications of equation 8 beginning at the farthest point upstream and working downstream.

Another important form of solution for equation 9 is that for dissolved oxygen (DO) concentrations downstream from a point discharge of BOD producing material such as sewage waste. The original formulation of this relationship was derived in 1925 by Streeter and Phelps. DO is an important variable because it is a good indicator of the general "health" of a stream and its ability to support a stable ecosystem. The DO system is quite complex, but again certain simplifying assumptions can be made.

The most important users of DO in an aquatic system are: BOD materials dispersed and dissolved in the water, oxygen demanding material in bottom muds (benthic demand), plant and animal respiration, and chemicals requiring oxygen to complete specific reactions (COD). Sources of DO are: reaeration from the atmosphere, photosynthesis, and oxygen inducement by human activity such as mechanical aeration.

The actual concentration of DO in a stream can reach a maximum value referred to as the saturation level. This value is a function of ambient temperature, salinity, and barometric pressure, but typically lies in the range of 7.0 to 14.0 mg/l in clean freshwater systems.



(Figure 11. River system divided into reaches)

A table of Saturation Values of Dissolved Oxygen versus temperature may be found in Kittrell (1969).

The difference between the saturation value, D_s, and the actual DO concentration is termed the DO deficit, D. The basic model is in terms of this DO deficit,

$$D = D_o e^{-k_2 \frac{x}{u}} + \frac{k_1 L_o}{k_2 k_1} \left(e^{-k_1 \frac{x}{u}} - e^{-k_2 \frac{x}{u}} \right)$$

where D = dissolved oxygen deficit (mg/1)

D_o = dissolved oxygen deficit at (mg/1) time X = 0: usually taken to be at the outfall

x = distance downstream (meters)

u = stream velocity (e.g., meters/sec)

e = Naperian constant (approximately 2.71282)

k_1 = rearation rate coefficient (days^{-1})

k_2 = deoxygenation rate coefficient (days^{-1})

L_o = ultimate first stage BOD (mg/1)

$$= \frac{BOD_5}{(1 - e^{-k_1 \frac{x}{u}})}.$$

Given values for L_o (or BOD_5), D_o, u, k_1, and k_2, this equation can be solved for the oxygen deficit at any point downstream from the outfall. The actual DO concentration is given by

$$DO = D_s - D$$

The results of this model are graphically shown in Figure 12. The graph is referred to as an "oxygen sag curve" because of its characteristic shape.

Notice that the results are different for varying temperatures. This is due to temperature variations in k_1, k_2, and L_o described by

$$k_1 = k_1(20) \quad \theta_1(T-20)$$

$$k_2 = k_2(20) \quad \theta_2(T-20)$$

and

$$L_o = L_o(20) \quad (0.02T + 0.6)$$

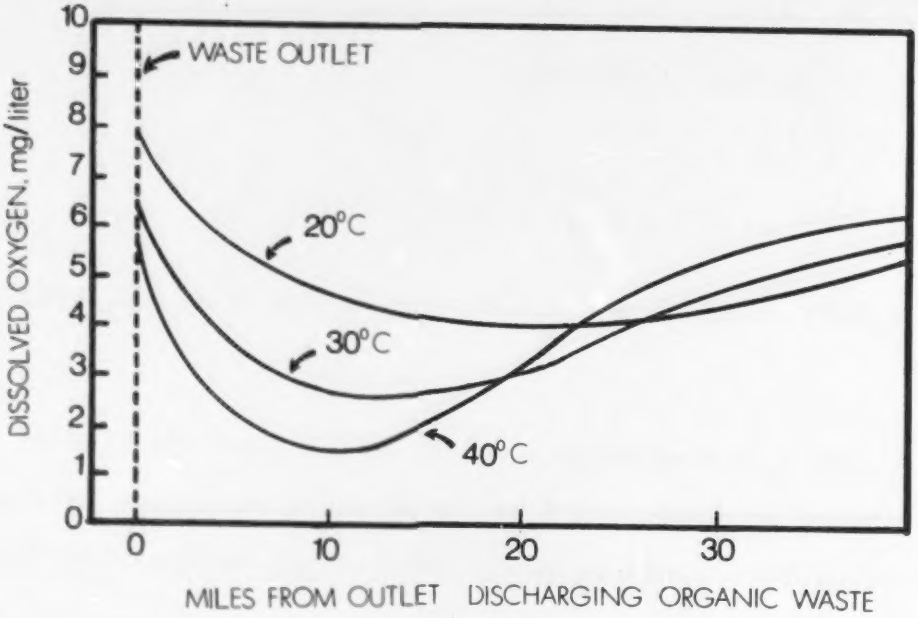
where $k_1(20)$, $k_2(20)$, and $L_o(20)$ are values of k_1, k_2, and L_o at $20^\circ C$.

θ_1 and θ_2 are constants which depend upon the kind of water system being studied, and T is temperature in degree centigrade.

Values for θ_1 and θ_2 are: (Hydrologic Engineering Center, 1972)

θ	Range	Most Often Used
θ_1	1.047 - 1.140	1.047
θ_2	1.000 - 1.150	1.016

Typical values for $k_1(20)$ and $k_2(20)$ are (Hydrolic Engineering Center, 1972):



(Figure 12. Relation between temperature and oxygen profile (Canter, 1977).

Type of Waste	$k_1(20)$ Range (days^{-1})
Slowly degradable waste	0.10 - 0.20
Domestic waste	0.20 - 0.25
Readily degradable waste	0.25 - 0.50

Stream Type	$k_2(20)$ Range (days^{-1})
Small ponds and backwater	0.12 - 0.23
Sluggish streams and large lakes	0.23 - 0.34
Large streams of low velocity	0.34 - 0.46
Large streams of normal velocity	0.46 - 0.69
Swift streams	0.69 - 1.15
Rapids and waterfalls	1.15 - greater

A particular point of interest is the minimum concentration and its location on the sag curve. This can be found by methods of simple calculus as:

$$X_{min} = \frac{\ln\left[\frac{k_1L_o}{k_2-k_1} - D_o \quad k_2/ \quad \frac{k_1{}^2L_o}{k_2-k_1}\right]}{(k_2 \quad - \quad k_1)}$$

$$D_{min} = \frac{k_1L_o}{k_2} \qquad e^{-k_1 X min/u}$$

This model can be applied to successive river reaches in the same manner as described earlier for conservative substances.

The model as presented above can be expanded to include additional terms for : nitrogenous BOD, distributed sources of BOD, photosynthesis, algal respiration, bethnal demand, diurnal variation, sedimentation, and other effects. Interested readers should consult the listed references, especially Thomann (1972).

Thermal Pollution. Mathematical models of varying degrees of complexity have been developed to predict the persistence of heat in quiescent waters, flowing streams, estuaries, and the ocean (Edinger and Geyer, 1965). It is beyond the scope of this presentation to analyze the detailed aspects of each of these models. An example has been published on the use of a simplified temperature-predictive equation for calculating downstream temperatures following a waste heat discharge into a flowing stream (Federal Water Pollution Control Administration, 1968). Excellent reference materials are available on the subject of thermal pollution (Krenkel and Parker, 1969a, 1969b, 1969c).

Lake Models. The above discussion concerned river or stream systems; however, many of the same principles can be applied to models of lakes, but the processes involved become considerably more complicated. The assumption of one dimension variation in space is no longer valid, and dispersion/diffusion effects must be considered. Likewise, the effects of ecosystem production and respiration usually assume a greater significance in lake systems.

Several different models for various substances in large and small lakes have been developed. Nutrients such as phosphorous and nitrogen have been modeled (Dettmann, 1973, and Lorenzen, 1973).

More complicated biotic models have been constructed for Lake Michigan (Canale, et al., 1975) and other lakes. Generalized lake modeling considerations are addressed by Park (1974).

Limitations of Water Quality Models. The deficiencies of water quality models, like all models, are primarily due to the simplifying assumptions made in their construction and use.

The assumption of variation in species concentration in only the downstream direction may not always apply. Similarly, plug flow is an idealized concept not found in natural systems.

Solutions usually rely on a steady state assumption, i.e., the concentration does not vary with time within the period considered. In reality waste discharges can assume any of several different forms of time dependent behavior from cyclical to purely stochastic functions and all combinations in between. Chemical reactions are assumed to be a first order decay to another non-polluting substance. More complicated reactions are usually neglected.

Even with these limitations, however, water quality models do provide a better methodology for prediction of changes in the aquatic environment than intuitive guesswork. Ecis analysts should seriously consider their use in the analysis of environmental benefits.

Computer-based Water Quality Models. As with the Air Quality Models, the Water Models require varying amounts of data input and computer capability. Stream quality models useful in determining concentrations of various conservative and non-conservative pollutants in different bodies of water have been computerized.

Other models are available to simulate runoff in both urban and rural situations. Detailed below are two models, one for stream quality and the other for runoff simulation. These models are available through various public agencies.

Stream Quality Model QUAL II. The Stream Quality Model QUAL II was developed by the Water Resources Engineers, Inc. in Texas for the Federal Environmental Protection Agency. It is a comprehensive stream model that is able to produce both dynamic and steady state simulations of a stream or river system. It can (1) simulate steady state temperature; (2) dynamically simulate all water quality constituents, either conservative or non-conservative; (3) input initial conditions for dynamic simulation in a continuous rather than a step-wise fashion; (4) operate either in English or metric units; (5) produce a series of tables depicting the concentrations of the modeled pollutants at different periods of time; and (6) produce printer plots of selected parameters versus distance; each plot may contain from one to five different parameters.

QUAL II can simulate any combination of the following constituents:

Chlorophy *a*
Phosphorus
Benthic Oxygen Demand
Dissolved Oxygen
Radioactive Substances
Nitrogen (Ammonia + Organic Kjeldahl), Nitrite, Nitrate)
Carbonaceous BOD
Dissolved Oxygen Demand
Coliforms
Conservative Substances

If either phosphorus or the nitrogen cycle are not being simulated, the model presumes they will not limit algal growth. The model is fairly data-intensive to run for large systems but has the advantage of incorporating many interactive effects not accounted for in simple hand calculation models.

Illinois Urban Drainage Area Simulator (ILLUDAS). The Illinois Urban Drainage Area Simulator (ILLUDAS) was developed by the Illinois State Water Survey. When storm rainfall occurs in a rural area, much of it soaks into the earth, and the remainder runs off to the nearest stream or body of water. The excess surface runoff may cause some temporary flooding on the land surface, along ditches, drainageways, and small stream channels. In urban settings, much of the natural landscape is covered with paved streets, rooftops, and other paved areas. The remaining natural earth is generally covered with grass lawns. In addition to flooding considerations, the effects of such runoff on aquatic systems may be significant due to sewage plant overloading, distributed source input of pollutant (especially true for nutrients, sediments, and other solids), and streamflow characteristics. Although few ecis's will need such a model, it is available and relatively easy to use.

Water Quality Assessment Procedure. Basic steps associated with prediction of changes in the water environment are:

1. Determine types and quantities of water pollutants emitted for all alternatives.

2. Determine the existing water quantity and quality levels for the surface watercourses in the area.

Examine the frequency distributions and the median and mean data for both water quantity and quality. If possible, consider historical trends of water quality. Note particularly the low flow utilized by the IEPA and local agencies for maintenance of water quality standards.

3. Document unique pollution problems that have occurred or are existing in local surface watercourses.

4. If relevant, describe groundwater quantity and quality in the area, noting the depth of the groundwater table and direction of groundwater flow. Identify major local uses of groundwater, and delineate historical trends for groundwater depletion and pollution.

5. Assemble summary of key meteorological parameters for the area, noting particularly the monthly averages of precipitation, evaporation, and temperature.

6. Relate applicability of effluent standards and required treatment technology. State whether the receiving streams are water-quality limited or effluent limited. Consider time schedules required for attaining applicable water quality standards.

7. Summarize the organic waste load if applicable. Also procure extant information on inorganic, thermal, sediment, and bacterial waste loads as necessary. Identify known point sources of pollution, focusing specifically on unique discharges or wastewater constituents. Also enumerate the types of water uses in the area and summarize the quantities involved.

8. Determine the mesoscale impacts by calculating estimated daily quantities of water pollutants for the alternatives and compare these to existing waste loads. Determine the percentage increase in these waste loads. Note existing water quality parameters that are good or poor relative to current standards which may be affected by the proposed alternatives.

9. Determine the microscale impacts by calculating specific downstream concentrations resulting from conservative pollutants, dissolved oxygen concentrations resulting from non-conservative (organic) pollutants, and temperatures resulting from thermal discharges as applicable. Compare calculated downstream concentrations with applicable water quality standards. Check if applicable effluent standards are met for existing facilities, or consider how they will be brought into compliance. In the case of new sources, identify necessary technology for compliance with new source performance standards. Use water quality models as applicable.

REFERENCES

Busse, A. D., and J. R. Zimmerman, 1973, User's Guide for the Climatological Dispersion Model (CDM). Technical Publications Branch, U.S. EPA (Environmental Monitoring Series, EPA,R4-73-024). Research Triangle Park, North Carolina, 144 p.

Canale, R. P., L. M. Depalma, and A. H. Fogel, 1975, Mathematical-Model of Lower Food Web in Lake Michigan: Abstracts of Papers from the American Chemical Society, 169 (21).

Canter, Larry, 1977, Environmental Impact Assessment. McGraw Hill Book Company (Series in Water Resources and Environmental Engineering), New York, 331 p.

Concaildi, G. A., A. S. Cohen, and R. F. King, 1976. ANL/HIWAY: An Air Pollution Evaluation Model for Roadways. Energy and Environmental Systems Division, Argonne National Laboratory, Argonne, Illinois, 141 p.

Cunniff, P. F., 1977, Environmental Noise Pollution. John Wiley & Sons, Inc., New York, 210 p.

Daetz, Douglas, and Richard Pantell, 1974, Environmental Modeling: Analysis and Management. Dowden, Hutchinson and Ross, Inc. (Benchmark Papers on Electrical Engineering and Computer Science), Stroudsburg, Pennsylvania, 407 p.

Dettmann, E. H., 1972, Model of Seasonal Changes in Total Nitrogen Concentration in the Lake Wingra Water Column. NTIS (EDFB-IBP-72-12), Washington.

Edinger, J. E., and J. C. Geyer, 1965, Heat Exchange in the Environment. Edison Electric Institute (Publication No. 65-902), New York.

Federal Water Pollution Control Administration, 1968, Water Quality Criteria. Washington.

Fulle, Douglas, 1976, A Comparison of Three Stability Classifications Systems Using Surface and Radiosonde Data for Four Cities in the Western U.S. American Meteorological Society (Third Symposium on Atmospheric Turbulence, Diffusion, and Air Quality, October 19-22, 1976, Raleigh, N.C.). Boston, 141-148.

Hydrologic Engineering Center, 1972, Water Quality Determinations (Vol. 11 in the series Hydrologic Engineering Methods for Water Resources Development). U. S. Army Corps of Engineers, Davis, California.

Khanna, S. B., 1976, Handbook for UNAMAP. Walden Division of Abcor, Inc., Wilmington, Maryland, 108 p.

Kittrell, F. W., 1969, A Practical Guide to Water Quality Studies of Streams, U. S. Department of the Interior (Federal Water Pollution Control Administration CWR-5), Washington, 135 p.

Krenkel, P. A., and F. L. Parker, 1969a, Biological Aspects of Thermal Pollution: Proceedings of the National Symposium of Thermal Pollution, Nashville, Tennessee, August 14-16, 1968. Vanderbilt University Press, Nashville, Tennessee.

Krenkel, P. A., and F. L. Parker, 1969b, Engineering Aspects of Thermal Pollution: Proceedings of the National Symposium of Thermal Pollution, Nashville, Tennessee, August 14-16, 1968. Vanderbilt University Press, Nashville, Tennessee.

Krenkel, P. A., and F. L. Parker, 1969c, Thermal Pollution: Status of the Art (Report #3, National Center for Research and Training in the Hydrologic and Hydraulic Aspects of Water Pollution Control). Vanderbilt University Press, Nashville, Tennessee.

Lorenzen, M., 1975, Phosphorus Model for Lake Washington: Abstracts of Papers from the American Chemical Society, 169 (32).

Lowry, I. S., 1964, A Model of Metropolis. Rand Corporation, Santa Monica, California

Mancuso, R. L., and R. L. Ludwig, 1972, User's Manual for the APRAC-1A. Stanford Research Institute (NTIS PB 213091), Menlo Park, California, 119 p.

Nemerow, N. L., 1974, Scientific Stream Pollution Analysis. McGraw Hill Book Company, New York, 358 p.

deNevers, N., and R. J. Morris, 1975, Rollback Modeling: Basic and Modified: Journal of the Air Pollution Control Association, 25(9)943-947.

Park, R. A., 1974, Generalized Model for Simulating Lake Ecosystem: Simulation, 23(2)33.

Perkins, Henry, 1974, Air Pollution, McGraw-Hill, Inc., New York, 407 p.

Portelli, R. V., 1976, A Comparative Study of Experimentally Measured Atmospheric Stability and "Star Program" Predicitions. American Meteorological Society (Third Symposium on Atmospheric Turbulence, Diffusion, and Air Quality, October 19-22, 1976, Raleigh, N.C.) Boston, 124-129.

Roberts, Howard A. and Sievering, Herman, 1977, A Guide to Environmental Benefits Assessment in Economic Impact Studies, Illinois Institute for Environmental Quality, Chicago, Illinois.

Smith, Maynard, 1968, Recommended Guide for the Predicition of the Dispersion of Airborne Effluents. American Society of Mechanical Engineers.

Thomann, R. V., 1972, Systems Analysis and Water Quality Management. McGraw-Hill Book Company, New York, 286 p.

Turner, D. B., 1970, Workbook of Atmospheric Dispersion Estimates. U. S. EPA, Office of Air Programs, Research Triangle Park, North Carolina, 84 p.

Urban Diffusion Model Computer Program, 1972, U. S. EPA, Technical Publications Branch (Ecological) Research Series, EPA-650/3-73-011), Research Triangle Park, North Carolina.

Williamson, Samuel, 1973, Fundamentals of Air Pollution. Addison-Wesley Publishing Company, Reading, Massachusetts, 472 p.

Zimmerman, J. R., and R. S. Thompson, 1975, User's Guide for HIWAY: A Highway: Air Pollution Model. U. S. EPA (Environmental Monitoring Series, EPA-650/4-74-008), Research Triangle Park, North Carolina, 68 p.

CHAPTER FOUR (a): ENVIRONMENTAL BENEFIT/DAMAGE ASSESSMENT

Section I - Introduction

Some regulations, when adopted, lead to improvement in environmental quality while others lead to degradation in quality. Still others may lead to simultaneous improvements and degradation (e.g., improvements in air quality at the expense of water quality). In order to minimize confusion, much of the chapter is written as if the regulations, when adopted, lead to improved environmental quality.

The general approach relies on comparison of estimates of environmental quality expected to prevail in the near future with and without the regulation. Since most regulations deal with a single pollutant, the procedure is based on a comparison of the amount of the single pollutant in the environment with and without the regulation.

The procedures developed in this chapter begin with the assumption that the contractor has made estimates of environmental quality likely to prevail with and without the regulation. Of course, the level of geographic disaggregation to be used in the environmental quality assessment (see Chapter Three) depends on the procedures used to evaluate environmental benefits and damages. Thus, the procedures of Chapter Three and of this Chapter are not as independent as the description of the procedures pretends.

Throughout this chapter, the following general plan is suggested:

(i) Establish estimates of environmental quality with and without the regulation under evaluation using geographic areas appropriate for the pollutant and regulation in question.

(ii) Determine the changes in environmental quality (i.e., exposure) to be experienced by: a) different geographic areas, b) different demographic groups, c) manufacturing and commercial property, d) crops, e) domestic and wild animals, f) drinking and process water, etc.

(iii) Estimate the effects of the changes in environmental quality on each of the classes identified in (ii). For example: 1) changes in death rates, 2) changes in disease incidence rates, 3) changes in property value, productivity, maintenance expense, equipment life, etc., 4) kind and quantity of crop losses, 5) kind and quantity of animal (including fish and birds) loss, 6) other effects.

(iv) Estimate a dollar value for each of the quantitative effects listed in (iii) above.

The environmental effects that seem to be uppermost in the minds of most individuals are health effects. No ecis can be accepted without some discussion of potential health effects. However, while mortality and morbidity effects are clearly of primary importance, other effects are potentially important, too. This Chapter is organized so that each major section develops procedures for estimating the effect of the regulation on:

mortality and morbidity, recreation, aesthetics and amenities, environmental accidents, irreplaceable assets, and physical damage. The first two steps in the procedure described above are carried out once for each regulation. Then the effects of exposure to changed environmental quality are estimated and finally an attempt is made to measure the effects in dollar terms. Because of the lack of information, qualitative statements will sometimes have to be used in place of the quantitative estimates called for in steps (iii) and (iv) above.

Often, it will be impossible to measure the effects of a regulation on any or all of the effect categories listed above. Yet, some accounting of the effects is considered desirable. Then, the contractor might assume that the effects of a change in environmental quality as perceived by individual citizens, may be reflected in different values associated with property located in areas of differing environmental quality. In short, environmental effects are reflected in market prices for residential property to the extent they are perceived by the individuals.

There is no reason to think that improved environmental quality should have any effect on property values other than through improved health, property preservation, aesthetics, recreation, etc. associated with improved environmental quality where the property is located. Thus, increased property values associated with improved environmental quality act as a summary variable measuring the combined perceived influence of health, property preservation, etc. If separate measures of, say, health effects are made and the property value procedures also followed, some double counting may result.

This possibility is discussed further below.

The format of this Chapter then is:

Section IVb1 Property Values
Section IVb2 + 3 Mortality and Morbidity Effects
Section IVb4 Recreation Effects
Section IV5 Aesthetic and Amenity Effects
Section IV6 Environmental Accidents
Section IVb7 Irreplaceable Assets
Section IVb8 Physical Damage Effects

This is the first edition of this Handbook. Chapter Four has not been completed and only the sections on Property Values and on Mortality and Morbidity Effects are now included. These sections have undergone several revisions and have purposely been presented at different levels of technical and notational complexity. This edition should be considered a first experiment as we search for the proper balance between simplicity and theoretical and conceptual correctness. If anything, we feel that the present version bends too far away from some important conceptual problems in an attempt to present procedures that can be used with immediately available data. Future revisions will reconsider this balance based on experience gained through application of the current version in construction of ecis's. They will also include detailed appendices providing background material on the procedures and detailing data sources and they will include material relevant to recreation, aesthetics and amenities, accidents, irreplaceable assets and property damage.

CHAPTER FOUR (b-1): THE IMPACT OF POLLUTION ON RESIDENTIAL PROPERTY VALUES

Section I - Introduction

There are many attributes of residential property that together determine its market value. It may have important attributes such as fertility, availability of fresh water, good buildings, etc. Other attributes associated with the land stem from its location relative to other land and to activities on those other pieces of land. Examples of the latter include: the distance to places of employment and/or the time it takes to get to places of employment, the time and distance to other activities like shopping, schools of various quality and to recreational activities. Other factors such as the characteristics of the neighborhood, scenic views and so on may also be determinants of the market price of land used, primarily, for residential purposes. Among those factors that may influence the market price of a piece of land are the environmental conditions in which it exists and must be used. Environmental quality will influence property values to the extent that environmental quality makes a difference in decisions made in the market for land. There are many reasons why environmental quality may influence the desirability of a piece of land used for residential purposes. If poor environmental quality is associated in the minds of the buyers and sellers with adverse mortality and morbidity for users of the land, then certainly this will be reflected to some extent in the market for land. If the environmental quality associated with the land makes living there less aesthetically pleasing than would otherwise be the case, then this aspect of the land, as perceived by the potential buyers and sellers, will be reflected in market prices.

Notice that whenever market prices are to be related to environmental quality, it is only the perceptions of environmental quality and perceptions of the effects of changes in environmental quality (e.g., on health), that are reflected in market prices. Thus, environmental quality may be considered awful by a health care professional but if not associated with the use of land by buyers and sellers of land, it will have no effect on the price of that land. As discussed in later sections, relationships between property values and environmental quality are necessarily made on a different basis than are, say, direct relationships between environmental quality and mortality and morbidity effects based on clinical dose-response functions.

If property values of residential land are to be related to measures of environmental quality, then property values must be assumed to serve as a surrogate for mortality, morbidity, and aesthetic effects related to changes in environmental quality. Of course, only perceived effects which are related to residential activities will be so captured. If a separate accounting of mortality and morbidity effects is being made as a part of the ecis process, then the property value analysis may double count some effects of the change in environmental quality expected to result from the regulation under evaluation. Those mortality and morbidity effects perceived to be associated with changes in environmental quality of residential use may be included both in changes in property values and in changes in mortality and morbidity effects. The problem of double counting is discussed further in later sections.

With all of the theoretical and econometric reservations discussed below and in the Appendix taken into consideration, the next two sections present step-by-step procedures for estimating the benefits associated with improved environmental quality through property value estimates. The first of the two immediately following sections outlines a procedure that might be used to develop estimates of relationships between property values and environmental quality. The next section suggests the manner in which this relationship might be used to convert property value estimates into state-wide benefits. As usual, the discussion is developed under the assumption that the regulation in question will "improve" environmental quality. If, instead, the regulation has as its purpose, the relaxation of an environmental standard, then the contractor must make the obvious reinterpretation, but the procedures remain valid.

Section II - Procedure For Relating Property Values to Environmental Quality

The contractor assigned the task of evaluating a particular ecis, before undertaking to carry out the procedure to be suggested in this section, should make sure that relationships involving the pollutant in question and property values do not already exist. The Appendix gives an overview to the available literature and discusses its shortcomings. This material should be read by the contractor at this point.

Since property values can be thought of as a surrogate for many other "results" of changes in environmental quality, there would be no need to explore property values if these other "results" could be measured directly. For example, if separate (and satisfactory) measurements of benefits from improved environmental quality associated with changes in mortality, morbidity, recreation, aesthetics and amenities, accidents, physical damage, irreplaceable assets, etc. can be made, then most of the reasons for environmental change affecting property values have been accounted for. Unfortunately, it is usually impossible to make all these separate measurements, and the contractor may have to rely on property value changes as a complex and imperfect surrogate.

Following Cohen, Fishelson, and Gardner,[4] who draw on some of Crocker's work,[6,7] the following relationship is postulated:

$$PR = a\left[z_1^{Q_1}\, z_2^{Q_2} \ldots z_j^{Q_j} \ldots z_p^{Q_p}\right]\left[X_1^{d_1}\, X_2^{d_2} \ldots X_m^{d_m}\right] U \qquad (1)$$

Here, the following notation has been employed:

PR = sale price plus incidental cost of purchase of land and dwellings - or some other measure of property values

z_j = concentration of pollutant j

a = a scale constant determined by the data

X_i = variables other than pollutant levels which determine property values. Examples are: income level of neighborhood, school quality in neighborhood, distance to CBD, size of house, size of lot, structural characteristics of house, etc.

Q_j, d_i = parameters whose values are to be estimated

U = a disturbance term

The logarithm of this equation is used in a linear regression analysis:

$$\ln PR = \ln a + \Sigma_{j=1}^{P} Q_j \ln z_j + \Sigma_{i=1}^{m} d_i \ln X_i + U' \qquad (2)$$

Notice that the rate of change of property values as the concentration of pollutant j varies, and all other independent variables are held constant (i.e., all z_f, X_i constant $f = 1, \ldots, P$; $f \neq j$, $i = 1, \ldots, m$), is $Q_j\ PR/z_j$ ($= \partial PR/\partial z_j$). Thus, the marginal willingness of the participant, in the land market which establishes PR, to pay for a small reduction in the concentration of pollutant j, other things being equal, is $Q_j PR/z_j$. For future reference, let the willingness to pay be q_j where:

$$q_j = Q_j\ PR/z_j \qquad (3)$$

This section is concerned with estimating q_j using (2) and (3). Later editions of this Handbook may develop interview techniques which can serve as an alternative to regressions for determining willingness to pay.

Step 1 This step and the others that directly follow in this section are almost independent of the regulation under evaluation. The first step is to identify all the pollutants to be included for use in Equation (2).

The contractor must have some estimates of the pollutant controlled by the regulation (say j = f).

Chances are that there will be little published information on the concentrations of other pollutants except perhaps for air pollutants like particulates and SO_2. However, as a large number of ecis are accumulated, the background of information on pollutant concentrations throughout the state will grow.

Realizing that property values are surrogates for a complex of variables, it is prudent to keep differences between geographic regions which form the basis for data collection as few as possible. For example, if no data on other pollutants that may influence property values is available, the contractor must assume these to be the same in all geographic regions. Consequently, the geographic units used may divide the population and residences of the state into: urban, suburban, town, and rural categories. In other cases, small units like census tracts or neighborhoods or even city blocks may be useful.

The result of Step 1 is to identify those pollutants on which there is concentration data for a statistically reasonable number of each kind of geographic unit. These concentrations will be used in (2) as the z_j values. (Notice that it is probably not correct to include only the pollutant in the present regulation.) Conceptually, tables are constructed as follows:

	Geographic Unit No.					
Pollutant Type	1	2	...	e	...	E
1						
2						
⋮						
q				z_{qe}^{g}		
⋮						
P						

z^g_{qe} = concentration of pollutant q in geographic unit number e of type g (g = urban (1), suburban (2), town (3), rural (4)) Because of lack of information, P will usually be small and so will E.

Step 2 This step is similar to Step 1 and involves identifying the X_i variables to be included. The contractor might start with a recent listing of variables presented by Leven and Mark (see Appendix). Their suggestions assume that geographic units the size of census tracts are appropriate. Here it was assumed that data from different census tracts within a given urban area could be used to establish the property value relationship. Cohen, Fishelson, and Gardner, as well as Crocker, used similar geographic units.

Structural Variables (from household interviews and census)

number of rooms
number of bathrooms
dummy variable for air conditioning
number of bedrooms
dummy variable for garage (0 or 1)
dummy variable for single or multi-family

Neighborhood Characteristics by Census Tract (from 1970 Census of Population)

% of population non-white
% of non-white population in highest adjoining tract
% of population in blue-collar jobs
% of population over 65
% of population under 20
% of housing units built in 1969-70
% of housing units built before 1939

% of families below poverty level
% of female-headed families
% of housing units renter occupied
% of housing units vacant entire year
median family income
FBI-indexed crimes per 100,000 population (from police districts)

Public Sector Measures

Crime clearance rate for the police district (from police district)
Expenditure per pupil in the school district (from schools)
Pupil-teacher ratio in the school district (from schools)

Access Measures (all in minutes)

Off peak driving time to nearest major shopping area from center of the census tract (from modal choice studies)
Peak driving time to the nearest major job center (from the center of the census tract) (from modal choice studies)
Actual travel time to the workplace of household head

As indicated above, it is not unreasonable to expect to be able to find data on many of the X_i variables for a variety of different sized geographic units. Frequently, these data are available from public agencies. Availability does not necessarily mean that these data can be obtained quickly and inexpensively.

This step results in tables indicating values for the X_i variables for the different geographic units. For example, X^g_{ie} would be the value of the ith variable in geographic unit of type g number e.

Step 3 Property value data must be obtained for roughly the same year for which X_{ie}^{g} and z_{je}^{g} data were obtained and for the same geographic units.

Property value data can be obtained from market transactions, perhaps of FHA dwellings, from assessment data, and from the census. The former is preferred but may be the most difficult to find. Aggregate values of owner-occupied and vacant, for-sale dwellings in each tract are reported by the Census Bureau. The Appendix contains more details. Aggregate monthly contract rent of renter-occupied and vacant, for-rent dwellings is also reported. The monthly rent is multiplied by 12 to convert it to annual rent. The property value is assumed to be equal to the present value of an infinite stream of annual rent payments. If a 10% interest rate is used, the property value is 11 times the annual rent. Census figures relate only to housing units for which values or rents were reported by their owners or occupants in the Census. This represented about 85% of the total in 1970.

Step 4 Assume, at this point, that the contractor has collected data to satisfy Steps 1, 2, and 3 for the same geographic units and for roughly the same years. This then constitutes what is often called cross-section data. The use of this form of data assumes that the resulting relationship will be stable over time.

Using Equation (2), the property value data is regressed on the pollutant concentration data and on the other property value determinants data (i.e., the X_i).

A separate regression is run for each of the importantly distinctive geographic units. For each type of geographic unit (g), the regression yields values for the parameters Q_j^g and d_i^g.

In particular, values of Q_f^g, the parameters associated with the pollutant of concern in the regulation being evaluated, are determined. A fundamental assumption of this kind of regression is that the so-called independent variables are statistically independent. As discussed in the Appendix, this is unlikely to be the case in practice. In particular, the location of property relative to recreational and industrial sites influences the time and cost of getting to and from recreation and work, but also influences air quality given the emissions at their sources. Thus, air quality "independent" variables and "independent" location variables will probably exhibit multi-colinearity. This, in turn, means that the coefficients (i.e., the Q_j) associated with air quality variables do not accurately capture the overall effect of air quality on property values. (If SO_2 is $j = 3$ and distance to CBD is $k = 2$, so z_3 = conc of SO_2 and X_2 is distance to CBD; then multi-colinearity means that:

$$\partial PR/\partial z_3 = Q_3 \left[PR/z_3 \right] + (\partial PR/\partial X_2)(\partial X_2/\partial z_3) = PR\left[\frac{Q_3}{z_3}\right] + PR\left[\frac{d_2}{X_2}\right]\left[\frac{\partial X_2}{\partial z_3}\right]).$$

When such multi-colinearity is present, it is an error to consider only $Q_3 \left[PR/z_3\right]$ as the marginal willingness to pay for a unit reduction in SO_2 concentration. In this farfetched example, property values have been influenced directly by the reduction in SO_2 concentration, z_3, resulting from the regulation and also indirectly because the regulation has caused shifts in employment location resulting in changes in X_2. There seems to be no foolproof technique for avoiding these difficulties in general.

Step 5. The final step in the procedure is to use the results of Step 4, the Q_f^g values, and Equation (3) to produce values of q_f^g which has been defined as a surrogate for the willingness to pay for a unit change in the concentration of pollutant f for residences in geographic units of type g (e.g., urban, town, etc.). The regression yields a single value for Q_f^g for each type of geographic unit but the willingness to pay depends on the property value and on the pollutant level according to (3). For our purposes, it is convenient to have a constant value of willingness to pay for each geographic unit. Accordingly, the contractor is to compute the average property value per dwelling unit across all geographic units of type g, $\overline{PR^g}$ and the average pollutant concentration across all geographic units of type g, $\overline{Z_f^g}$.

Then:

$$q_f^g = Q_f^g \ (\overline{PR^g}/\overline{Z_f^g}$$

is the sought after willingness to pay for each type of geographic unit. For comparison purposes, Cohen, Fishelson and Gardner found willingness to pay estimates, per \$1000 of property value, ranging from \$1.75 to \$3.21 per ug/m^3 for particulates and \$0.00 to \$4.63 per ug/m^3 for SO_2 in Chicago.

Section III - Procedure For Calculating Benefits

This section is based on the benefit equation: (4)

$$B = \Sigma^{P}_{j=1} \Sigma^{n}_{i=1} \Sigma^{T}_{t=1} \left\{ H_i \left[q_j (-\Delta z^1_{jit} - (-\Delta z^2_{jit})) \right] /(1+r)^t \right.$$

This equation was used for SO_2 and particulants in the Chicago area by Cohen, Fishelson and Gardner (see Appendix).

B = total statewide present value of benefits from regulation under study

r = an appropriate social rate of discount

H_i = total value of residential property in geographic unit i

q_j = willingness to pay per unit of concentration of pollutant j per dollars worth of property. (From Step 5)

z^1_{jit} = concentration of pollutant j in geographic unit i in year t with the regulation

z^2_{jit} = same as z^1_{jit} but without the regulation

$\Delta z^1_{jit} = z^1_{jit} - z^1_{jit-1}$ = improvement in concentration of pollutant j between year t-1 and year t in geographic unit i with the regulation. Notice that normally we would expect $\Delta z^1_{jit} < 0$ for most t.

Δz^2_{jit} = same as Δz^1_{jit} but without the regulation

T = planning horizon in years

n = number of geographic units in state

P = number of pollutant types

Equation (4) is too complicated and requires too much data for general use by the ecis contractor.

Some suggested simplifying assumptions follow:

A1 Most regulations deal with a single pollutant so that $P = 1$ and the subscript j above can be dropped.

A2 Most comparisons of with and without regulation situations refer to a "typical" year sometime in the future after the reactions to the changes required by the regulations reach "steady state". Make this assumption. Then $T = 1$ and the term" $(-\Delta z^{1}_{jit} - (-\Delta z^{2}_{jit}))$ becomes zero and Equation (4) can be simplified.

Using both A1 and A2, the benefit equation becomes:

$$B = \Sigma^{n}_{i=1} \; H_{i}q \, (z^{2}_{i} - z^{1}_{i}) \qquad (5)$$

The term $z^{2}_{i} - z^{1}_{i}$ is the difference (i. e. change) in the concentration of the pollutant in question in the target year and for geographic unit i resulting from the regulation.

The remaining element of potential difficulty is that of defining a useful and appropriate geographic unit for analysis. If the regulation deals with air pollution, perhaps census tracts or counties or some other socio-economic unit, for which property value data can be obtained, will be appropriate. If the transport properties of the pollutant are confining (e.g., race track noise), then perhaps small units, such as city blocks, are most appropriate. The contractor must consult with Institute staff and decide on a suitable geographic unit. Since he will develop his concentration data (i.e., z^{1}_{i}, z^{2}_{i}) using this geographic unit, he should also consider other analyses which will usually use these same data (e.g., mortality and morbidity effects).

Step 6. Given the decision on the geographic unit, the contractor makes estimates of z^1_i and z^2_i. He establishes a most likely value $\bar{z}^1_i$, with the regulation and $\bar{z}^2_i$, without the regulation. He also establishes (but see Step 7 first) values of α^1_i, α^2_i, β^1_i and β^2_i which are defined from the following:

Prob (actual value of $z_i > \alpha_i$) = .10 and

Prob (actual value of $z_i < \beta_i$) = .10.

Of course, the contractor does not have the probability distribution of pollutant concentration in each geographic area with and without the regulation. The α^1_i, α^2_i, β^1_i, β^2_i are based on the contractor's subjective estimates of the distribution.

Step 7. Using the most likely values from Step 6 the contractor computes the following for each geographic unit:

$$\left[\frac{\bar{z}^2_i - \bar{z}^1_i}{\bar{z}^2_i}\right] = Z_i.$$ (The proportionate change in pollutant concentration)

All geographic units for which $Z_i < .05$ are eliminated from further analysis (for those eliminated areas, there is no need to establish α^1_i, α^2_i, β^1_i, β^2_i).

Step 8. Step 7 will eliminate the need for studying major portions of the State of Illinois for most regulations. For those areas with $Z_i > .05$, the contractor must establish a value of H_i (for use in equation 5)' usually from Census information.

For convenience, it is to be assumed that the H_i are measured without error.

Step 9. The value of q is obtained from Step 5.

Step 10. Referring only to those geographic units for which $Z_i > .05$, it is to be assumed that the estimates of $\bar{z}^1{}_i$, $\bar{z}^2{}_i$, $\alpha^1{}_i$, $\alpha^2{}_i$, $\beta^1{}_i$, $\beta^2{}_i$, heretofore considered part of a subjective continuous distribution, form two discrete probability distributions:

$$P\left[z^1{}_i = \bar{z}^1{}_i\right] = .80, \quad P\left[z^1{}_i = \alpha^1{}_i\right] = P\left[z^1{}_i = \beta^1{}_i =\right].10;$$

and

$$P\left[z^2{}_i = \bar{z}^2{}_i\right] = .80, \quad P\left[z^2{}_i = \alpha^2{}_i\right] = P\left[z^2{}_i = \beta^2{}_i =\right].10.$$

Step 11. The contractor generates a distribution of B, the statewide change in property values associated with the regulation, as follows:

a) Using a random device, select a value of $z^1{}_i$ and $z^2{}_i$ from the distribution appropriate for geographic unit i.

b) Compute B.

c) Repeat a) and b) and present a histogram for B.

d) From the histogram develop a most likely value for B, $\bar{B}$ and values α_B and β_B.

e) Present these results with suitable explanation.

Discussion. The benefit Equation (5) computes, for each geographic unit, the dollar amount participants and potential participants in the market for residential property would be willing to pay for a reduction in pollutant concentration of $z^2{}_i - z^1{}_i$.

The units of $z^2_i - z^1_i$ are concentration units (e.g., micrograms per cubic meter). The units of the willingness to pay coefficient for the pollutant under study are dollars per microgram per cubic meter per dollar of residential property. The total value of residential property in geographic unit i is H_i. Therefore:

$$\left[\ \$ \text{ of property}\ \right]\left[\frac{\$ \text{ willing to pay}}{\$ \text{ of property - mg/m}^3}\right]\left[\frac{\text{mg}}{\text{m}^3} = \right]\$ \text{ willing to pay.}$$

Many of the conceptual compromises that must be made in order to employ this procedure are reviewed in the Appendix.

In Step 6, it is suggested that the contractor take some direct notice of the uncertainties inherent in the pollutant concentration estimates. He is assumed to be able to estimate a most likely value $\bar{z}$ for each geographic unit with and without the regulation. Should he be unable to do this step, there can be no benefit analysis. He is also asked to estimate a worst and best case λ_i, ℓ_i with and without the regulation. We have suggested a particular definition of best and worst based on the contractor's subjective probabilities.

In terms of separation between with and without the regulations, the ideal situation would be:

$$\ell^1_i < \bar{z}^1_i < \lambda^1_i < \ell^2_i < \bar{z}^2_i < \lambda^2_i$$

Under these circumstances, the procedure suggested for eliminating geographic units from further analysis in Step 7 will work well. However, should there be substantial overlap between the two subjective probability distributions, some change in the 5% criterion must be considered.

For example, if $\ell^2_i < \bar{z}^1_i$ for a substantial portion of areas for which $Z_i < .05$ then the contractor might consider raising the 5% criterion. On the other hand, if $\ell^2_i < \alpha^1_i$ for only a very few of the geographic units for which $Z_i < .05$, then the contractor and the Institute staff might consider lowering the 5% criterion.

In Step 11, the contractor is expected to employ a Monte Carlo type of procedure to generate a distribution for B. This would normally be done on a computer but the procedure illustrated in the following simple example could also be considered. Suppose there are only two geographic units with $Z_i > .05$. Let $\bar{z}^1_1 = 10$, $\bar{z}^2_1 = 15$, $\alpha^1_1 = 12$, $\ell^1_1 = 8$, $\alpha^2_1 = 20$, $\ell^2_1 = 11$, $\bar{z}^1_2 = 100$, $\bar{z}^2_2 = 150$, $\alpha^1_2 = 120$, $\ell^1_2 = 80$, $\alpha^2_2 = 200$, $\ell^2_2 = 110$. Then the distribution can be portrayed as follows:

z^1_1: 12, 10, 10, 10, 10, 10, 10, 10, 10, $\textcircled{8}$

z^2_1: 20, $\textcircled{15}$, 15, 15, 15, 15, 15, 15, 15, 11

z^1_2: 120, 100, $\textcircled{100}$, 100, 100, 100, 100, 100, 100, 80

z^2_2: $\textcircled{200}$, 150, 150, 150, 150, 150, 150, 150, 150, 110

These represent the result of "ten idealized independent trials" for each of the four situations (i.e., two geographic units with or without the regulation).

The contractor makes a random selection from each line. Let the circled values represent one such selection. Then:

$z^2_1 - z^1_1 = 15 - 8 = 7$ and
$z^2_2 - z^1_2 = 200 - 100 = 100.$

If $q = 1$ and $H_1 = 1 \times 10^6$ while $H_2 = 1 \times 10^4$ then:

$$B = (1)\ (10^6)\ (7) + (1)\ (10^4)\ (100) = 8 \times 10^6 \text{ dollars.}$$

This process is repeated using "new drawings" from the distributions with each repetition resulting in a value for B. These results would be reported in the form of a histogram. A sufficient number of repetitions is to be made to develop the histogram to the point where estimates of $\bar{B}, \alpha_B$ and β_B can be determined.

Monte Carlo simulation is a commonly accepted procedure for estimating distribution functions of key entities. In addition to the difficulty of establishing the subjective distributions of the z_i on which the simulation is based, there is the built-in assumption of statistical independence between the distribution of z^1_i and z^2_i and z^1_j and z^2_j etc. It has been suggested that the distribution be approximated by a particularly simple discrete distribution with 80% of the "weight" located at $\bar{z}_i$ and 10% at each of α_i and β_i. Other, more sophisticated alternatives are possible. Furthermore, the procedure just outlined assumed independence among the distributions. This means that if a drawing from the distribution for z^1_1 yields α^1_1, there is no reason to expect that this drawing means anything with respect to a drawing from the distribution of z^1_2, for example. Under some circumstances, it might be expected that a large value for z^1_1 would be associated with a large value of z^1_2. Then, once $z^1_1 = \alpha^1_1$ is drawn, the probability with which z^1_2 is equal to α^1_2 should be greater than .10 since the same external influence that affect the z_1 values might also affect the z_2 values.

No such potential interdependencies (resulting in conditional probabilities) are included here.

One final aspect of the 5% rule used in Step 7 deserves a comment. It is possible that the 5% rule could eliminate from further consideration some geographic units of the state with the bulk of residential property. In other words, the values of H_i for those geographic units for which $Z_i > .05$ may be a very small fraction of the state. When this seems to be the case, the contractor should explore the effect of lowering the criterion of Step 7 from .05 to .04. After all, the .05 criterion of Step 7 is based on an intuitive feeling about the accuracy of data and on the realization that the contractor must have some systematic way in which to limit the number of geographic units that must be studied.

The step-wise procedure presented in this section necessarily represents a compromise between the conceptually correct procedures and the simplistic, inexpensive and quick procedures often found in practice. Resource and time limitations enforced upon the Institute and its contractors have required that our compromise be biased in favor of procedures that require reasonable time, effort, and expertise. It is expected that the contractor will take the time to make himself conversant with notation and approaches used in the procedures set forth in this section and in subsequent sections even if he is not initially familiar with them. Some familiarity with the more complex arguments of the Appendix should also be acquired.

Extensions. Although it may seem that the step-by-step procedure is meant to deal only with air pollution, it is applicable to other pollutants, including water pollutants, as well.

Water pollution may take the form of chemical pollution, physical pollution, and/or thermal pollution. In any case, the existence of the pollutant may cause increases in costs among users of the water for drinking and other household uses, as well as for industrial uses. These costs are of two kinds: (1) those that are incurred through efforts to remove the pollutant prior to using the water, and (2) those associated with having the body of water (stream, lake, river, pond, etc.) polluted. Some of the latter costs are associated with: stench, unsightly appearance, harm to wild life, fish, vegetation; other harm to the body of water for recreational purposes; health effects associated with the existence of polluted bodies of water. In some cases, such as with purification of drinking water, increased purification costs can be traded off against costs associated with poor health or unpleasant taste.

By and large, it seems safe to assume that costs of the first kind will be taken account of by the contractor on an individual basis as in Chapter 5 of this handbook. Most of them would be associated with industrial and commercial activities. The exception would be individual residential efforts to purify drinking water at the home faucet. On the other hand, the costs of the second type are primarily those associated with non-industrial "uses" of water, and can be thought of as influencing the economy through their effect on residential areas.

It is natural, then, to attempt to relate these aspects of water pollution to residential property values. Indeed, there seems to be little choice in the matter, since "damage functions" which relate pollution to active recreational uses of water or to more vaguely defined aesthetic uses have not been established. Thus, there is inadequate knowledge of the whole set of relationships concerning why people "consume" leisure-type environmental activities, and how real and/or perceived water quality affects these consumption activities.

It has been traditional in cost-beneft analysis to exclude increments in property values arising from public investment for which there is no corresponding increase in the output of goods and services. The exemption is based on the idea that pecuniary externalities or simple income transfers should not be included in an overall benefits measurement. On the other hand, if there is an output of goods or services, a more direct measure than property value increments is usually sought. However, if the "increase" is in terms of recreational or aesthetic "services", there is usually no direct measure available.

There has been some empirical work which supports the assumption that property values are positively related to water quality.[1,2,3]

---

[1] David, Elizabeth and William B. Lord, Determinants of Property Value on Artificial Lakes, University of Wisconsin, Dept. of Agricultural Economics, 1969.

[2] Dornbusch, David,M. and Stephen Barrages, Benefit of Water Pollution Control on Property Values, U.S. EPA, EPA-600/5-73-005, Oct. 1973.

[3] Hochman, Oded and Rick Milles, "Estimating a Hedonic Price Function of Property Value along River Basins in the Chicago SMSA with Particular Emphasis on Water Quality," Working Paper, 8/29/77.

However, Freeman[4] found a dearth of competent studies in the realm of water pollution's effects on land values.

The immediate effects of changes in water quality on residential property values, if any, will be reflected in values of property located very close to the water. Of course, water for general recreation the size of Lake Michigan will affect a much larger geographic area by a change in its water quality than would an equal change in water quality in a smaller body of water.

The regression suggested by equation (2) should be carried out with the inclusion of water-borne pollutant concentrations among the z_j variables. However, the distance from a body of water must be used to relate these concentrations to different geographic regions such as census tracts. In keeping with the rather primitive state of the art, it is suggested that water pollutant concentration variables be included in the regressions based on equation (2) only for those census tracts in which bodies of water (streams, lakes, ponds, etc) exist. Then benefits from improvements in water quality of the kind designated above as being associated with property values and not being accounted for separately would be generated only in those census tracts. (Recall that improvements that influence commercial processing costs or drinking water costs are to be considered elsewhere by the contractor. They may be doublecounted, through their effect on property values, in those census tracts in which bodies of water exist.)

---

[4] M.Freeman writing in Peskin, Henry and Eugene P. Seskin (editors) Cost-Benefit Analysis and Water Pollution Policy, The Urban Institute, 2100 M Street, N.W., Washington, D.C. (Pub.No.URI 77000).

Within these limitations, regressions reflecting water quality and property values using equation (2) can be developed and the results used in computing the benefits using equation (5) in the step-wise manner suggested above.

The suggested restriction of property value effects resulting from changes in water quality to those census tracts in which bodies of water exist is arbitrary. In some cases, it may be desirable to extend the geographic range of water quality to, for example, census tracts in which bodies of water exist, plus all census tracts having a common boundary, with a census tract in which a body of water exists. Just as the appropriate level of geographic disaggregation depends on many aspects of the contractor study; so, too, does the appropriate range of effects for changes in water quality.

REFERENCES

(1) Anderson, J. E., and T. D. Crocker, "Air Pollution and Residential Property Values," *Urban Studies*, 8, pp. 171-180 (1971).

(2) Barrett, L. B., and T. E. Waddell, *Cost of Air Pollution Damage: A Status Report*, U. S. Environmental Protection Agency, Publication No. AP-85, Research Triangle Park, North Carolina, 1973.

(3) Bezdek, William E., *et al.*,"Professional Appraisers" Judgment of the Effect of Air Pollution on Property Values", The Social Psychology Laboratory of the University of Chicago, sponsored by the Public Health Service, Department of Health, Education and Welfare, January, 1969, PB-245 751.

(4) Cohen, Alan S., Gideon Fishelson, and John L. Gardner, *Residential Fuel Policy and the Environment,* Ballinger Publishing Co., Cambridge, Mass., 1974.

(5) Cohen, Alan S., *et al.*, "Economic Impact Study of the Proposed Motor Vehicle (in-Use) Noise Regulation," Illinois Institute for Environmental Quality, Document No. 76/10.

(6) Crocker, Thomas D., *Urban Air Pollution Damage Functions: Theory and Measurement*, National Technical Information Service Publication No. PB-197 668, Springfield, Virginia, 1970.

(7) David, Elizabeth, "Lakeshore Property Values: A Guide to Public Investment in Recreation", *Water Resources Research*, Aug., 1968.

(8) David, Elizabeth and William B. Lord, *Determinants of Property Value on Artificial Lakes*, University of Wisconsin, Dept. of Agricultural Economics, 1969.

(9) Dornbusch, David M., and Stephen Barrages, *Benefit of Water Pollution Control on Property Values*, U. S. Environmental Protection Agency, EPA-600/5-73-005, Oct. 1973.

(10) Feller, I., and J. P. Nelson, *Economic Aspects of Noise Pollution* Center for the Study of Science Policy, Pennsylvania State University, 1973.

(11) Freeman, Myrich, in Peskin, Henry, and Eugene P. Seskin, editors, *Cost-Benefit Analysis and Water Pollution Policy,* The Urban Institute, 2100 M. Street, N.W., Washington, D.C., Pub. No. URI 77000.

(12) Freeman, Myrich, "On Estimating Air Pollution Control Benefits from Land Value Studies", Journal of Environmental Economics and Management, 1, pp. 74-83 (1974).

(13) Gamble, Hays B., et al., "Community Effects of Highways Reflected by Property Values", Pennsylvania State University, Institute for Research on Land and Water Resources, DOT-FH-11-7800, August, 1972.

(14) Hershaft, A., editor, "Critical Review of Estimating Benefits of Air and Water Pollution Control," Final Report, Contract No. 68-01-2821, prepared for the U.S. Environmental Protection Agency by ENVIRO Control, Inc., October, 1976.

(15) Hochman, Oded, and Rick Milles, "Estimating a Hedonic Price Function of Property Value along River Basins in the Chicago SMSA with Particular Emphasis on Water Quality," Working Paper, 8/29/77.

(16) Jordening, David L., "Estimating Water Quality Benefits", U. S. Environmental Protection Agency, EPA-600/5-74-014, August, 1974.

(17) Kain, J. F., and J. M. Quigley, "Measuring the Value of Housing Quality", Journal of the American Statistical Association, 65, 1970.

(18) Krutilla, J. V., and A. C. Fisher, The Economics of Natural Environments, Johns Hopkins Press, Baltimore, Maryland, 1975.

(19) Lave, L. in Kneese and Bower, editors, Environmental Quality Analysis, Johns Hopkins University Press, Baltimore, Maryland, 1972.

(20) Leven, Charles L., and Jonathan H. Mark, "Revealed Preferences for Neighborhood Characteristics", Urban Studies, 14, pp. 147-159 (1977).

(21) Mohring, H., "Alternative Welfare Gain or Loss Measures", Western Economic Journal, 9, pp. 349-368 (Dec. 1971).

(22) National Academy of Sciences, Air Quality and Automobile Emission Control, Vol. 4, Costs and Benefits of Auto Emission Control, Washington, 1974.

(23) Nelson, J. P., "Residential Choice, Hedonic Prices, and the Demand for Urban Air Quality", paper presented at the Third World Conference of the Econometric Society, Toronto, Canada, August 16-20, 1975.

(24) Nelson, Jon P., The Effects of Mobile-Source Air and Noise Pollution on Residential Property Values, Center for the Study of Science Policy, Institute for Research on Human Resources, Pennsylvania State University, University Park, Pa., Report #DOT-TST-75-76, April, 1975. (Executive summary PB246 980).

(25) Peskin, Henry M., and Eugene P. Seskin, editors, *Cost-Benefit Analysis and Water Pollution Policy*, Urban Institute, 2100 M Street, N.W., Washington, D.C., 1975, Publication No. URI 77000.

(26) Polinsky, A. M., and S. Shavell, "Amenities and Property Values in a General Equilibrium Model of an Urban Area", Working Paper No. 107-5, The Urban Institute, July, 1973.

(27) Polinsky, A. M., and S. Shavell, "The Air Pollution and Property Value Debate", *Review of Economics and Statistics*, 57, pp. 100-104 (1975).

(28) Randall, A., et al., "Benefits of Abating Aesthetic Environmental Damage", *Agricultural Experiment Station Bulletin No. 618*, New Mexico State University, Las Cruces, N.M., 1974

(29) Ridker, Ronald G., *Economic Costs of Air Pollution*, Praeger Publishing Co., New York, N.Y., 1977.

(30) Ridker, Ronald G., and J. A. Henning, "The Determinants of Residential Property Values with Special Reference to Air Pollution", *The Review of Economics and Statistics*, 49, pp. 246-256 (1967).

(31) Rosen, S., "Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition", *Journal of Political Economy*, *82*, pp. 34-56, (Jan.-Feb. 1974).

(32) Salmon, R. L., *Systems Analysis of the Effects of Air Pollution on Materials*, National Technical Information Service Publication No. PB-209 192, Springfield, Virginia, 1972.

(33) Smith, E. K., and T. A. Deyak, "Measuring the Impact of Air Pollution on Property Values", *Journal of Regional Science*, 15, p. 3 (December 1975).

(34) Smith, V. K., *The Economic Consequences of Air Pollution,* Ballinger Publishing Co., Cambridge, Mass. 1976.

(35) Tiebout, C., "A Pure Theory of Local Expenditures", *Journal of Political Economy*, *64*, pp. 416-424 (1956).

(36) Waddell, Thomas, *The Economic Damages of Air Pollution*, United States Environmental Protection Agency, EPA-600/5-74-012, 1974.

(37) Wieand, Kenneth F., "Air Pollution and Property Values: A Study of the St. Louis Area", *Journal of Regional Science*, *13*, pp. 91-95 (1973).

Section II - A Framework for Estimating the Health Benefits of Pollution Control

There are numerous problems associated with the development of consistent and generally applicable measures of benefits from reduced environmental pollution brought about through a variety of pollution control regulations. The regulations themselves are quite different one from another. Some deal with general pollution control, (e.g., a regulation on the permitted emissions of sulfur dioxide) where the impact of the regulation is distributed throughout the state. Other regulations deal with specific exemptions to particular kinds of regulation, where the impact is restricted to an area very close to the polluter asking for the variance. Different kinds of pollutants naturally lead to different areas of impact. Consequently, it is difficult to prescribe one methodology that should be used for an evaluation of each and every regulation. Although regulations may result in increased or in decreased pollutant levels, the following discussion is written from the point of view of a regulation which results in reduced pollutant levels. The suggested procedures apply in either case but where increases in pollutant are expected, the obvious inversions must be made.

The attempt here is to provide a framework within which most regulations can be evaluated with respect to mortality and morbidity effects. The framework is presented in a step by step format. However, each step contains substantial discussion of the procedures being proposed.

Step 1. The ecis contractor must generate environmental quality estimates, by geographic unit for future years with and without the regulation under evaluation. The appropriate size of the geographic unit depends on the form of the regulation and on the pollutant. A general SO_2 regulation, for example, might call for estimates by census tracts or by county, while a regulation on racetrack noise might call for environmental quality estimates by city block, etc. A tentative decision on the appropriate geographic unit must be made in the early stages of the analysis through consultation between the contractor and the Institute staff as the contractee. It is subject to change as the contractor attempts to complete the following steps in the evaluation process.

Some regulations will affect so many pollution sources that it is impossible for the contractor to study each of them regardless of the geographic unit chosen for analysis. For example, consider the question of evaluating a regulation which deals with pollutants produced by residences. In these cases, the contractor and Institute staff must identify "typical or average" geographic regions. A commonly used breakdown is: urban, town or suburban, and rural. Two strategies are available for developing the "typical" rural, town and urban areas.

Each individual in the state can be designated as residing in one of the three classes of community. Then a profile of the typical urban, rural or town community is a composite of the individuals living in such communities throughout the state. Since this section is concerned with health effects, the composite must specify relevant demographic characteristics, which may be useful in later steps, such as: percentage non-white, percentage over 65, percentage under 18, etc.

Which characteristics of the population of the typical communities are most important will depend upon the form of the regulation and the pollutant.

A second alternative is to identify actual urban, town and rural areas as "typical" of their class throughout the state. Then, these "typical" areas are studied as case studies.

Step 1 should result in estimates of concentrations of the pollutant under study, by the chosen geographic unit, with and without the proposed regulation. The contractor should report these estimates as: the most likely value, the worst value and the best value. Although he may not be able to justify it empirically, the contractor should think of the worst value as a level of pollutant concentration that would be exceeded with frequency of at most 1 time in 10 while the best case is a pollutant concentration such that the actual concentration would fall short of it with frequency at most 1 in 10.

$$\left\{\text{Prob.}\left[\ C_{\text{actual}} \geq C_{\text{worst}}\right] = \text{Prob.}\left[\ C_{\text{best}} \geq C_{\text{actual}}\right] = .10\right\}$$

The equation defining the best and worst concentration is read as follows: The probability (subjective and based on the contractor's and Institute's studies and experience) that the actual concentration (C_{actual}) of the pollutant in question will be equal to or greater than the concentration to be designated as the "worst" (C_{worst}) is equal to the probability that the actual concentration will be less than or equal to the concentration designated as best (C_{best}) and both are equal to .10. This equation defines C_{worst} and C_{best}. The estimates of pollutant concentrations with and without the regulation provide the key data for subsequent steps in the ecis process.

Even if mortality and morbidity effects are unimportant or cannot be measured, this step must be carried out. By connecting geographic units with identical or nearly identical pollution concentration values on a map, isopleths can be approximated with and without the regulation.

Step 2. It is important for the contractor to specify what will be considered a "significant" level of the pollutant under investigation. Ideally, the significant level is the minimum pollutant concentration expected to have some adverse effect on human health. With this kind of information and with the environmental quality estimates for different geographic areas developed in Step 1, the contractor could identify those geographic areas that warrant further study in order to establish the mortality and morbidity effects of the proposed regulation.

The current state of the art does not permit an unambiguous determination of the "significant" level of most pollutants. Therefore, the contractor and the Institute staff must agree on some approximate procedure, some alternatives of which are discussed below. The contractor must explicitly state choice of alternative and reasons for selecting it in the report.

For some pollutants, primary standards of pollutant concentrations have been set and these might be used as the "significant" concentration level to establish the geographic areas affected by the regulation as far as mortality and morbidity are concerned.

If a value for the "significant" level of a pollutant is to be taken from an outside source, primary standards, when available, are the least controversial choice. There are some alternatives.

One alternative that makes use of readily available information, but information collected for other purposes, is the use of TLV (threshold limit values) values "suitably" modified. It must be noted that many sources - even ACGIH (American Council of Government and Industrial Hygenists) which developed TLV's - feel that using them to establish a "significant ambient level" of pollutant is inappropriate. TLV's are based on 40 hours per week exposure to healthy workers. Consequently, an adjustment of the published TLV values of (TLV) (40/168) (.01) is suggested if the contractor persists in using them. This adjusts for continuous exposure over the week (40/168) and the (.01) adjusts for general population sensitivity versus that of healthy workers. Even with this adjustment, the use of TLV's should be thought of as a last resort. Their only advantage for the ecis process at hand is their availability.

A third alternative is to choose as the "significant" pollutant level the usual background level of pollutant plus some factor for statistical "noise".

It should be noted that there are many other possibilities of the same type that may be considered by the contractor and by the Institute staff. For example, the USEPA publication, "Multimedia Environmental Goals" lists goal levels of concentrations for 650 pollutants and provides technical data sheets on each one. The State of Illinois Toxic Substances List has goals for approximately 300 pollutants (similar to federal DOT list).

There is also a Federal Toxic Substances List which contains goals for 7000 substances where the goals are based on skin tests performed on animals.

Each of the alternatives suggested above is based, in one way or another, on establishing a minimum harmful pollutant concentration. The "significant" level for a given pollutant will vary widely from list to list reflecting major differences in philosophy, data, and objectives between the various list makers. Consequently, for most studies, the following procedure is recommended.

In Step 1, the contractor must estimate pollutant levels throughout the State with and without the proposed regulation. In this step, he identifies those geographic units for which the regulation is expected to make a 5% or greater change in the concentration of the pollutant in question. Later he will analyze the population of the geographic units so identified to compute the mortality and morbidity effects of the regulation. The 5% change is to be based on the estimates of the most likely pollutant levels with and without the regulation (from Step 1).

This procedure has the advantage of avoiding, or at least postponing, consideration of what absolute levels of a pollutant cause deleterious health effects. The 5% difference is somewhat arbitrary and may have to be altered under some circumstances. For example, with geographic units discussed one at a time (and for a regulation resulting in a reduction in pollution), suppose the following values of estimates result from Step 1:

best case with regulation, concentration = a;
most likely concentration with regulation = b;
concentration for worst case with regulation = c;
best case without regulation, concentration = d;
most likely concentration without regulation = e;
concentration for worst case without regulation = f.

The ideal situation in terms of identifying the geographic units for analysis is when $a < b < c < d < e < f$. In this case, the contractor must only consider those geographic units for which $(e-b)/e \geq .05$. However, when $d<b$ for a substantial fraction of the geographic units for which $(e-b)/e \geq .05$, then the contractor in consultation with the Institute staff should consider raising the 5% criterion. If, on the other hand, $d<c$ for only a *very few* of the geographic units for which $(e-b)/e \geq .05$, then the contractor and the Institute staff might consider lowering the 5% criterion.

Thus, in Step 2, the contractor identifies those areas of the State to be studied in detail for the evaluation of benefits. If the typical area procedure is used, the portion of those areas requiring further study is identified. There may be overlap of areas not considered in the typical area procedure but this error will usually not alter the accuracy of the overall study. Each area of the state falls into one of the "typical" area categories so the "typical" area analysis can be scaled up to state level.

Step 3. Now that the geographic units to be studied have been identified, the contractor must decide what characteristics of these units and their associated population are important for the rest of the analysis.

The recommendation here is that the population be disaggregated only when the contractor and/or the Institute staff have strong reasons for doing so.

Thus, the minimal result of Step 3 must be the number of people in each geographic unit identified in Steps 1 and 2. For some pollutants, different population segments may have different susceptibility. A common disaggregation of the population in this case is by age, for example, under 12, over 65 and other. Here, Step 3 would yield the number of individuals in each susceptibility class in each geographic unit expected to experience at least a 5% change in concentration* of the pollutant in question as a result of the proposed regulation.

Step 4. This step organizes the information available as the result of the preceding steps. For each geographic unit (within the State or within the "typical area") for which a 5% or greater change in most likely pollutant level is expected to result from the regulation (or otherwise identified in Step 2), the contractor has:

(i) the number of people (perhaps disaggregated by susceptibility class)

(ii) the pollutant levels with and without the regulation including rought indications of uncertainty in their estimates.

Notice that usually there will be a great many geographic units throughout the state that will be eliminated from further consideration in Step 2.

---

*For expository purposes, it is assumed that the 5% criterion discussed in Step 2 is used to identify geographic areas for further study. We continue to make this assumption throughout succeeding steps. If some other rule is used to identify the area, it can be substituted without changing the description of that Step.

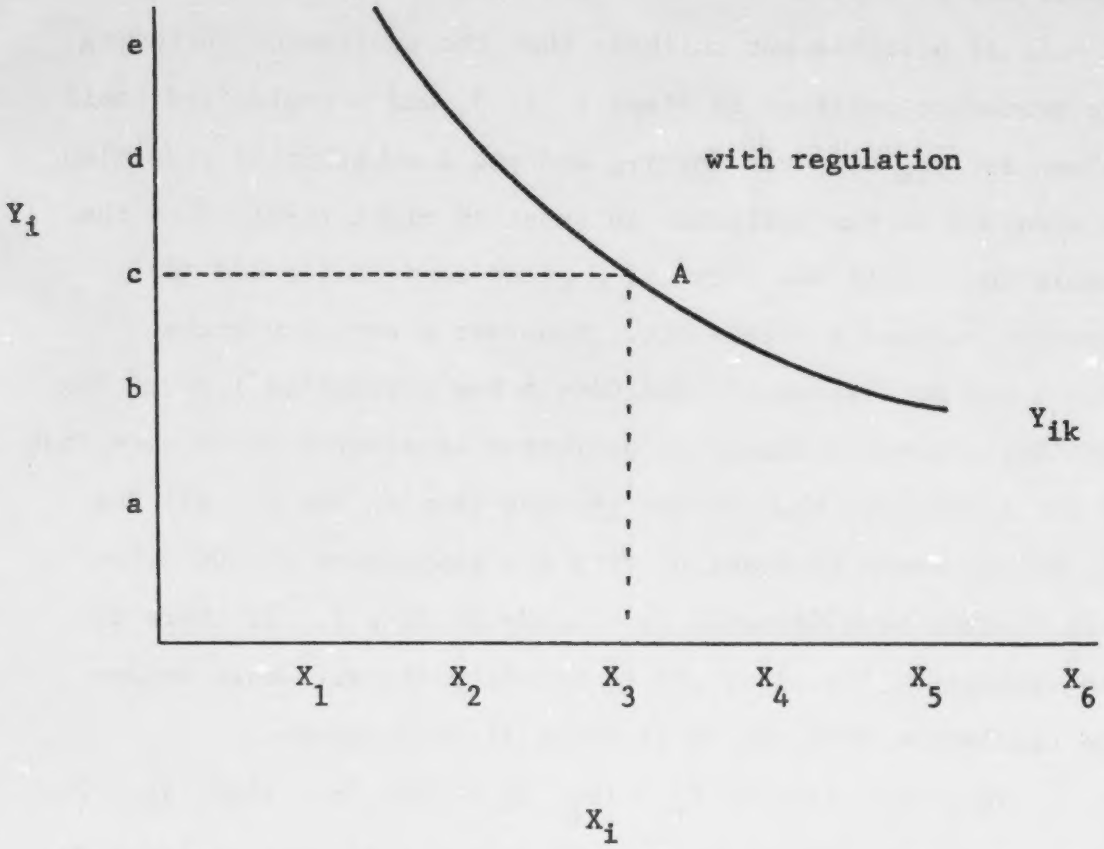
No population data on these areas is required and they play no role in the balance of the ecis evaluation.

Suppose that the pollutant concentrations are measured on an interval scale. The appropriate scale and units depend on the pollutant. For example, suppose the interval is .01 microgram per cubic meter. Then the intervals are from 0 to 0.01, from 0.01 to 0.02 and so on. Designate X_i as the ith one of these intervals. Then, X_3 would represent the interval between 0.02 and 0.03 micrograms per cubic meter. This interval and the units of measurement are purely illustrative and will depend upon the kind of pollutant being investigated.

Let Y_{ijk} represent the number of individuals in susceptibility category k residing in geographic unit j exposed to pollution level of at least X_i. That is, Y_{2jk} would include all those individuals living in geographic unit j of susceptibility class k who are exposed to pollution concentrations in the range 0.01 to 0.02 micrograms per cubic meter or more. The results of the previous steps permit computation of the Y_{ijk} levels with and without the regulation, throughout the significantly affected areas of the state. These results can be summarized by summing the Y values over the geographic units of the state (i.e., $Y_{ik} = \Sigma_j Y_{ijk}$) resulting in Y_{ik} values which are the statewide totals of individuals in susceptibility category k exposed to pollutant level i or greater. Notice that the sum over j includes only those units of the state identified in Step 2 as experiencing a significant change in pollutant concentration. The summary statistics can be presented graphically, as illustrated in Figure 1.

Let Y'_{ik} be the number of individuals in susceptibility category k throughout the state who are exposed to pollutant at level i or greater without the regulation and who reside in areas identified in Step 2; while the same Y_{ik} notation without the prime will indicate the number of individuals in susceptibility category k throughout the state who are exposed to pollutant at level i or greater with the regulation and who reside in areas identified in Step 2. Then a statistic that indicates the reduction in exposure that is due to the regulation is $y_{ik} = Y'_{ik} - Y_{ik}$. Notice that, for the lower pollutant levels X_i, y_{ik} may be negative. The effect of the regulation may be to move some individuals from higher pollutant levels to lower ones. As X_i increases, the y_{ik} should also increase as there are fewer people in the higher pollutant category as a result of the regulation. The y_{ik} values can also be presented graphically.

The contractor is reminded that all summations over geographic units refer to sums over those areas identified as experiencing a significant change in pollutant concentration as a result of the regulation in question. Thus, Step 2 establishes a subset of the geographic areas of the state. The Y_{ik} and y_{ik} variables are the results of summations over that subset. There may be many people in the state in susceptibility category k exposed to the pollutant at concentration i or greater. Yet Y_{ik} may be very small because most of these people live in geographic areas where the change in pollutant concentration expected to result from the regulation is not significant (e.g., is less than 5%).



Point A indicates that $Y_{3k} = c$ or that the number of people throughout the state of Illinois living in areas identified in Step 2 in susceptibility class k (e.g., 65 or over) exposed to pollution levels of X_3 or more, with the regulation, is c. Other curves on this same graph can be drawn for other susceptibility classes and curves for the situation, without the regulation, can be added.

The areas in which they live are not included in the subset identified in Step 2.

It is possible but unlikely that the contractor following the procedure outlined in Steps 1, 2, 3, and 4 would find small values for y_{ik} and even for Y_{ik} and yet a substantial reduction in exposure to the pollutant in question might result from the regulation. This can occur if a great many people had their exposure reduced a little bit. Consider a two city state. City A has population 100 and City B has population 1,000. The regulation makes a change in pollutant concentration of more than 5% for A and less than 5% but greater than 4% for B. All the Y_{ik} values would be based on City A's population of 100 since City B would be eliminated from study in Step 2. If there is one susceptibility class and X_5 is the pollutant level before the regulation while X_2 is it after it in A, then:

$$Y_5' = 100,\ Y_5 = 0,\ Y_2' = 100,\ Y_2 = 100,\ y_5 = +100,\ y_2 = 0.$$

Y_5' is the number of people exposed to the pollutant at least to level X_5, without the regulation while Y_5 is similarly defined for the situation with the regulation. The balance of the notation follows this scheme.

However, the pollutant levels in B may fall from X_7 to X_6 because of the regulation. If the identification criterion of Step 2 had been 4% rather than 5%, the regulation would be evaluated on the basis of:

$$Y_7' = 1000,\ Y_7 = 0,\ Y_6' = 1000,\ Y_6 = 1000$$
$$Y_5' = 1100,\ Y_5 = 1000,\ Y_2' = 1100,\ Y_2 = 1100$$

and $y_7 = +1000$, $y_5 = +100$.

The contractor and the Institute staff must be aware of these possibilities and make reasonable adjustments in the stated procedures when they arise.

Step 5. At this stage of the analysis, the Y_{ik} or y_{ik} values may simply be presented in the report or they can be transformed into a variety of different measures including:

(a) the incidence of morbidity and mortality,

(b) a dollar cost index,

(c) a cost of personal defense, and/or

(d) a measure of the reduction in incidence of disease that would make the regulation worthwhile.

Each of these alternatives is briefly discussed below with the ultimate recommendation to be made by the contractor in consultation with the Institute staff.

Step 5a. Information must be obtained to indicate the anticipated effect (mortality and morbidity) on individuals in the susceptibility categories appropriate for the pollutant in question who are exposed to varying levels of the pollutant. If these kinds of data are available, they can be combined with the results of Step 4 to provide a specific estimation relevant to the actual population being exposed. Such estimates are in terms of death rates and various disease rates with and without the proposed regulation. This approach translates the y_{ik} information obtained from Step 4 into rates of incidence of various illnesses and deaths. Thus, a particular reduction in the number of individuals in susceptibility category k, who are exposed to the particular pollutant at level X_i is equivalent, for example, to a reduction in the number of individuals who contract respiratory disease requiring 30 days of hospitalization or more. It also may be equivalent to a number of individuals whose life is shortened by one year due to the onset of respiratory disease and to a number of individuals who experience discomfort necessitating one doctor's office visit, and so on.

Thus, each y_{ik} or Y_{ik} value is associated with a number of disease and death rates. Each of these several dimensions can, conceptually at least, be translated into annual dollar costs by associating costs with each incidence and death rate change related to the regulation (See Step 5b).

Whenever the data required to convert Y_{ik} and/or y_{ik} values into mortality and morbidity incidence rates are available, the contractor should pursue the procedures of Step 5a. He should present a summary of the changes in these rates attributable to the proposed regulation in his report. He may or may not continue this process to convert the changes in mortality and morbidity rates into dollar benefits.

It must be emphasized that the ecis contractor is expected to search for relationships between pollutant levels and mortality and morbidity incidence rates with the help of the Institute staff. The relationships may come from the health care community concerned with environmental aspects of health or they may be based on empirical relationships. The ecis contractor is not expected to develop these relationships himself. If the relationships are available, Step 5a should be carried out and mortality and morbidity rate changes reported.

If the relationships are not available, neither Step 5a nor Step 5b can be carried out and the ecis contractor should concentrate on Steps 5c and/or 5d.

The same considerations apply to translation of changes in mortality and morbidity rates into dollar benefits discussed in Step 5b. The ecis contractor, with the aid of the Institute staff, is to search for established dollar values and is to use them if satisfactory values can be found. He is not to attempt to establish these values himself.

In the evaluation of many regulations, the contractor and the Institute staff may well decide to stop after Step 4 due to lack of information required to perform and justify any portion of Step 5.

Data relating exposure by individuals in various susceptibility categories to rates of death and rates of onset of different diseases, ideally would be available from the health care community. For some very few pollutant-disease combinations, information may be readily available. For others, there may be fragmentary information available if it is vigorously sought. The EPA has performed several studies aimed at developing dose-response functions - many of them based on CHESS data. These are described briefly in the Appendix to this section. Efforts by Jaksch and Stoevener and by Seskin have resulted in forms of dose-response functions dealing with particulate and photochemical oxidant pollutants respectively. These studies are based on data obtained from two large pre-paid health care plans and additional information on them appears in the Appendix.

Carpenter also attempted to develop forms of dose-response functions based on hospital admissions.

Nelson, Knelson, and Hazelblad have filed away data on air pollution levels of sulfates, photochemical oxidants, CO, and NO_2 for the United States broken down into seven geographic regions. The population of each was broken down into four size categories ranging from metropolitan to rural. They also assembled dose-response functions from earlier studies - including CHESS - for the known or suspected effects of these pollutants. A few more details on this study, plus a full citation, appear in the Appendix.

Lave and Seskin have performed numerous studies over 1970 to 1975 and they have shown that death rates in different cities are higher and lower as the minimum or average - not peak - concentrations of particulate matter and sulfur compounds range from higher to lower levels. As a summary guide, Lave and Seskin find that reducing sulfur oxides and particulates by 50% would lower the death rate per year by at least 4%. Notice that the kind of work epitomized by Lave and Seskin develops an empirical relationship between pollutant concentrations and mortality rates. This information can be used in Step 5a as well as Step 5b.

Lave and Seskin collected data from 117 urban areas including readings of sulfate and particulate levels, and numbers of deaths due to various diseases. They also collected information on the population density, the percentage of population over 65 years of age, the percentage non-white, and the percentage with incomes under the poverty line.

Using multiple linear regression they showed that the four "social and economic" variables plus the two measures of pollution accounted for 83% of the variations in death rates among cities. (Note: This leaves little room for other pollutants.)

Cohen, Fishelson, and Gardner (Residential Fuel Policy and the Environment, Ballinger, 1974, pp.67) make use of the Lave and Seskin results to evaluate possible residential fuel regulations in the Chicago area. They present a table showing the expected extension of life (days) resulting from a one microgram per cubic meter reduction in particulate level. For example, one line shows white males, aged 35, in the base year (59/61) with expected age at death of 69.2 and an increased life of 1.4 days. The method of reporting results used by Cohen et al might be worthy of emulation by the ecis contractor.

Another potentially significant empirical study, primarily from a methodological standpoint, is that of Liu and Yu (see Appendix). They established one equation to determine the importance of all significant factors in death rates except air pollution. In a second equation, they found that SO_2 accounted for about 1% of the total death rate. Their work has been criticized by V. Kerry Smith (see Appendix).

Thus, there are some studies that develop dose-response relationships. In some cases, they are empirical relationships resulting from the use of linear regression or log-linear regression. Usually death rates are regressed on pollution levels and other explanatory variables using cross section data across urban areas.

The regression coefficients associated with the pollutant concentration define the "dose-response" function. Death rates are used as the independent variable because of limited data on disease incidence rates.

Unfortunately, for most pollutants, dose-response functions will not be available to the ecis contractor in spite of enthusiastic searches by the contractor and by the Institute staff. In these cases the contractor is advised to move on to Step 5c and/or 5d.

Step 5b. There are two possible ways to establish a cost index related to pollution levels:

(1) Using the same form of analysis as that of Lave and Seskin, obtain cross-section data on health care costs per capita (perhaps disaggregated by susceptibility category) that might be associated with pollutants, and regress these costs on pollutant levels and on other explanatory variables. For example, substitute health care and death costs for death rates in the Lave and Seskin work.

(2) Using the incidence rates for mortality and morbidity developed in Step 5a, associate costs with these rates.

Not a great deal of generally accepted work has been reported using either alternative but (2) is inherently more attractive and will be concentrated upon below.

If the contractor and the Institute decide that dollar values should be computed from the multidimensional incidence rates obtained from Step 5a, then care must be taken to state explicitly what aspects of the mortality and morbidity are considered and how they are valued.

For example, "early" death means a loss of productive activity which might be given a dollar value. It also means earlier burial and this earlier expenditure on burial is an opportunity cost. Of course, there is also the anguish of the family of the victim to which a dollar value might be associated using a kind of willingness to pay philosophy. Further, the illness leading to early death usually is associated with extra medical expenses. If dollar values are to be associated with reductions in mortality rates, some or all of these cost savings must be included. At present, there is no generally accepted way of computing these costs (see Appendix). Whatever procedure is adopted by the contractor, it should be explicitly spelled out in the report.

Future editions of this handbook will deal with the problem of associated health costs with rates of mortality and morbidity in more detail. In the meanwhile, the work of Cohen, Fishelson, and Gardner may be useful in addition to work reviewed in the Appendix. A discussion of the many nuances of the problem appear in a paper by Raiffa, Schwartz, and Weinstein. (Howard Raiffa, William Schwartz, and Milton Weinstein, "Evaluating Health Effects of Societal Decision and Programs" in Decision Making in the EPA, Vol. 11b, National Academy of Sciences, 1977.)

Step 5c. This step, where applicable, can be used in addition to or instead of Steps 5a and 5b. For some pollutants, it is possible for each individual to provide himself with protection. Then, a regulation that reduces the pollutant level saves all or part of the individual's expense of providing the same level of protection on his own.

Step 5d. The philosophy behind this step is based on the recognition that while the health care community often cannot provide dose-response functions and dollar costs of mortality and morbidity, it can provide some useful information. Suppose that the contractor has undertaken and completed estimates of all other costs and benefits (except mortality and morbidity) associated with a regulation and that costs exceed benefits annually by \$Z. (If these benefits should exceed costs, it may not be necessary to evaluate mortality and morbidity effects at all.) Further, suppose this pollutant causes or contributes to illness and/or death from respiratory disease. Insurance data can probably be obtained indicating the average medical costs of such a disease - at least in terms of its treatment. Suppose these costs amount to \$v per year per case of respiratory illness. Then Z/v = the number of cases of respiratory diseases that must be prevented by the regulation in order to make it "worthwhile".

This step, if it is to be done with any accuracy, requires that the results of Step 4 be available so that exposure of various segments of the population to the pollutant, with and without the proposed regulation are available. The contractor has developed values for Z and v. He and the Institute staff must now confront appropriate segments of the health care community (unless the contractor and/or staff can make the judgment) with the data from Step 4. Given the data from Step 4, he asks: what is the probability that the regulation will prevent (Z/v) cases of respiratory disease (in our example) annually?

It would be useful if the contractor could explore the feelings of the health care representative a bit further by asking the probability that the regulation would prevent (1.5 Z/v) and (.5 Z/v) cases as well.

The contractor should be especially concerned with probabilities of preventing cases fewer in number than Z/v. After all, v includes only the direct medical costs of the disease. All of the other important costs such as loss of work time, premature death, pain and discomfort are not included in v so the true costs of the illness caused by the pollutant in question may be quite a bit larger than v. Although the costs other than v may be very important for a public evaluation of the regulation, some of them may have been included in other phases of the ecis process and, therefore, already captured in Z. The contractor must guard against double-counting. Therefore, he should get from the health care community representative probabilities associated not only with Z/v cases but also Z/1.5v and Z/2v at least. Of course, if the probability for Z/v is very high (say .85 or above) there is no need to explore probabilities for smaller numbers of cases since it is reasonable to assume that the health benefits of the regulation more than overcome the deficit, Z.

The procedure suggested in this step draws only upon the work through Step 4 plus access to health care expertise. It is, therefore, potentially applicable to every regulation. Notice that it requires three kinds of information from the health care community:

(i) What illnesses are associated with the pollutant dealt with by the regulation?,

(ii) What is the average treatment cost of these illnesses?,

(iii) What effect does a change in pollutant exposure have on the number of cases?

The information contained in (iii) could be obtained from a dose-response function. Without that we seek the probability that the estimated actual number of cases without the regulation minus the estimated actual number of cases with the regulation is greater than or equal to Z/v, given the expected changed in the number of individuals in each susceptibility class exposed to various pollutant levels (i.e., the y_{ik} values from Step 4). By varying v over sufficiently wide range, the contractor can obtain the equivalent of a subjective dose-response function from the health care expert being interviewed.

Example Consider preparation of an ecis for a regulation involving hydrocarbon emissions. Sources here are spread throughout the state so typical areas, i.e., urban, town, rural will be used. The regulation specifies all the kinds of plants to be covered and it also specifies the minimum control technology required for each type of plant, its cost, and its efficiency in clearing up emissions. The State of Illinois permit system provides information on each emitting plant by industry class including its location, size, employment, and current emission level, e.g., annual lbs.

The contractor must first establish a satisfactory level of industry disaggregation (e.g., 2 digit SIC, 3 digit SIC, etc.). Then all the permits are placed into one of these categories according to the primary product. Within each category, place the plants into one of the geographic units (urban, town, rural) according to the location of the plant. Let X_{ij} be the number of plants of industry i located in geographic region type j (e.g., X_{32} might be the number of paint plants located in towns in Illinois) throughout the state. From state census data, determine the number of urban, town, and rural areas, n_j.

Compute the average numbers of each type of plant in each type of geographic area: $\alpha_{ij} = X_{ij}/n_j$. For each plant type and geographic area (i, j) combination, determine the total quantity of emissions, E_{ij}, based on permit data. E_{ij} is the pounds of hydrocarbons emitted by plants of type i located in geographic area type j. Also,compute the geographic average level of emissions: $e_{ij} = E_{ij}/n_j$ which is the annual poundage of emissions of hydrocarbons from plants of type i in a typical geographic region of type j. If needed, a kind of average emission per plant can be calculated as e_{ij} / α_{ij}.

Let C_{ij} be the total cost of compliance for all plants in Illinois of type i located in regions of type j. Then the total cost is: $\Sigma_i \Sigma_j C_{ij} = C$.

The average efficiency of the control technology for each type of plant is assumed known and is designated w_i. Emmissions in a typical urban area (j = 1), town (j = 2), and rural area (j = 3) then are:

$$\Sigma_i E_{ij}/n_j = \Sigma_i e_{ij} \text{ without the regulation}$$

and

$$\Sigma_i (1-w_i) e_{ij} \text{ with the regulation.}$$

The change in emissions caused by the regulation in each of the three kinds of geographic areas is then: $\Sigma_i e_{ij} w_i$. The change in emissions may be translated into changes in ozone exposure. We gloss over the complexities of this translation because they do not add to the illustrative features of this example. Let 0^o_j and $0'_j$ be the ozone concentration in area of type j before and after the regulation. With the projected changes in ozone concentrations for the typical urban, town, and rural area caused by the regulation, Step 2 has almost been completed. All that remains is to eliminate those kinds of typical areas for which $(0^o_j - 0'_j)/0^o_j \leq .05$ from further consideration. Illinois census data provide data on the number of people throughout Illinois who live in urban, town, and rural areas. This information plus n_j data permit us to compute the average population of each kind of area in the state still under study. For chemical pollutants like ozone, it may be important to disaggregate the average population by age, sex, color, income level, and prior respiratory disease. At this point, we have accomplished the first three steps of the suggested procedure. Step 4 is one of organizing and presenting the data generated by the first three steps so that it can certainly be carried out.

CHAPTER FIVE: POLLUTION CONTROL: COST ESTIMATION

5.0 Introduction

The purpose of this chapter is to assist the contractor in estimating pollution control costs and in presenting and interpreting such information in an ecis. Control "cost" as used herein is the direct cost to the "regulated" of complying with a proposed regulation. Such costs seem to fall within three general categories:

a. Direct emission control equipment might be added onto an existing process in either a new or existing facility.

b. The raw materials or the process itself might be modified to achieve compliance.

c. The existing process might be retained, but operated in a more-costly (less-efficient) manner and/or at reduced production levels.

Note that the foregoing costs are not intended to be restricted to industrial facilities. The regulated sources also might include residential, commercial, agricultural, or other categories. A proposed regulation might be directed at an individual facility or a diffuse statewide network of similar sources.

A number of steps are involved in estimating these pollution control related costs as part of an ecis:

1) Before selecting control alternatives and estimating costs, the contractor should estimate the extent, if any, of expected violation.

2) Selection of the control alternative should receive considerable attention. The alternative proposed by the parties to be regulated should be considered, but other alternatives also should be carefully investigated.

3) Having an idea of the extent of the control problem and feasible solutions, the contractor should review the categories of cost to be sure that all appropriate aspects of cost are included in his estimate.

4) Next, the contractor should consider selection of an estimation method. A hierarchy of methods is available: from highly-approximate generalizations to complex time-consuming detailed analyses of specific situations.

5) A variety of adjustments may be needed to alter the cost estimate because of uncertainty, inflation and technological innovation.

The remainder of this chapter discusses these steps in detail, along with a format for presenting results and a discussion of sources of basic cost data. Information needed to carry out the five steps is not yet available in centralized references, but a variety of government reports, previous ecis, and search services can sometimes provide useful information with minimum effort.

5.1 Degree of Violation

Identifying the degree of violation may require the comparison of source emission or effluent strength against the allowable emissions specified in the proposed regulations. Alternatively, violation may be defined in terms only of environmental quality, i.e., regardless of emission strength no violation occurs unless a receptor is experiencing a pollution concentration in excess of some specified level.

The first step in determining the extent of violations is to contact the Illinois Environmental Protection Agency (IEPA) which maintains a statewide inventory of air and water emissions (or discharges). But this information sometimes is dated and/or incomplete; thus on occasion the ecis contractor must look elsewhere to obtain an estimate of source strength.

Experimental emission measurements over a considerable time period usually provide the most meaningful assessment of source strength. In lieu of such direct measurement, the ecis contractor might attempt material balance calculations based on known feed and product streams.

A variety of references is also available. The best for air pollution is the voluminous, detailed, frequently updated, Compilation of Emission Factors (AP-42) published by U. S. EPA. When using such information, the ecis contractor should keep in mind that the information is derived from limited actual monitoring which may not be representative of particular facilities in Illinois.

Present and/or proposed regulations govern the control requirement. The ecis contractor should keep in mind that the control device must be sized to handle the maximum rather than the average legal emission. Also note that control requirements can be a function of raw material specifications. For example, Figure 1 indicates the increasing control efficiencies required as sulfur content in coal rises. Finally, note that control requirements, when based upon ambient environment quality, are a function of natural background and other contributing manmade emissions in the vicinity.

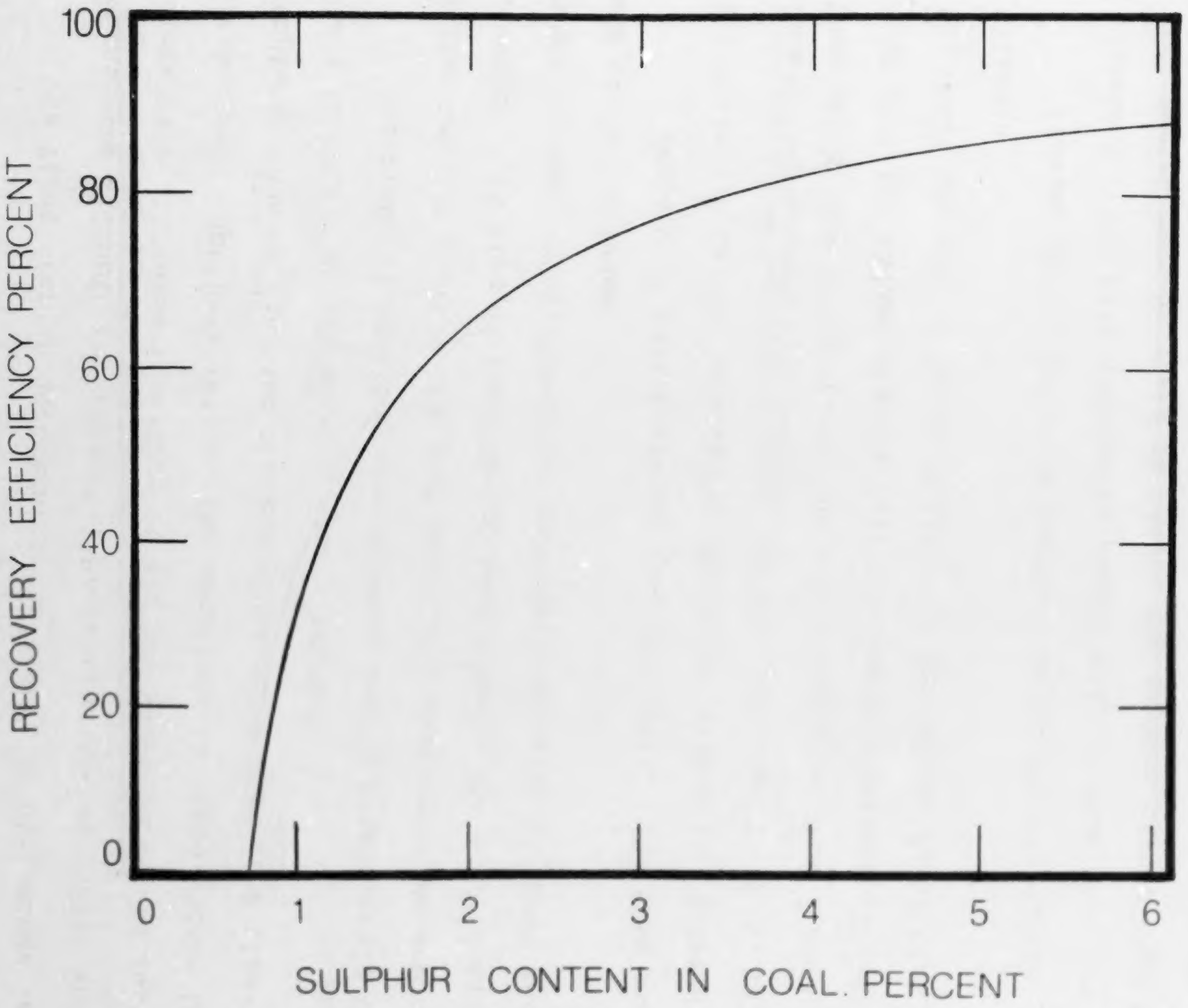


Figure 1. Recovery efficiencies required to meet new source performance standard

(for sulfur dioxide; 1.2 lb/10^6BTU)

5.2 Control Alternatives

There are many methods for complying with a wide variety of environmental regulations. Three control options general to most environmental problems may be employed, or a combination of these methods may prove optimal:

Direct Emission Control

This option entails the purchase and installation of control devices to attain compliance. There are many types of emission control equipment. U. S. EPA, as part of its Environmental Assessment (EA) Program, has contracted for definitive cataloging of alternatives, with alternatives keyed to specific pollutants and control problems. A continuing program is planned, with hundreds of alternatives to be explicitly defined during coming years. The first edition of the catalog is expected to be published in early 1978. In the meantime, the authors have published a progress report (Cameron Engineers 1977). Excerpts from this report can be obtained at the IIEQ library.

Process Change

Most observers and practitioners agree that process change is the most desirable means of pollution control. Real-life examples abound where a process change concurrently resulted in lower emissions and more profit. On occasion, process changes have eliminated toxic wastes or transformed them into valuable marketable products.

Such process changes can require considerable capital expenditure and lengthy time intervals prior to implementation. The ecis contractor may have inadequate background for meaningfully forecasting the likelihood of eventual process change. Still, some assessment of the likelihood of process change merits attention in many cases.

Production Limitations

Some industrial facilities can meet some emission regulations by reducing production levels. In such situations, there are usually no additional capital costs; control costs are more likely reflected in increased labor, maintenance, and fixed costs-per unit of production. These then are pollution control costs, and the contractor should estimate and present them as such.

5.3 Cost Estimation Components

Many factors contribute to the total cost of installation and operation of emission control equipment. For purposes of discussion, it is convenient to divide cost components into three sub-categories:

1. Installed Process Cost,
2. Annual Process Cost, and
3. Profitability

As implied by the designation, installed process cost represents the sum total of all expenses encountered in obtaining a physically installed process. In addition to the cost of the individual items of installed equipment, additional costs for design, construction, site development, etc. must be recognized as part of the installed process cost.

Environmental protection process costs, however, cannot be reasonably compared using only installed costs. Two processes with equivalent installed costs, for example, may have different useful lifetimes, operating personnel requirements, maintenance costs, tax credits, utility and raw material requirements, etc. All of these factors influence the net cost of the processes.

A correct basis of comparison requires examination of the costs incurred on a per unit time basis. For convenience, it is customary to examine these costs on a per year basis and refer to the net cost as the annual process cost.

Frequently, comparison of alternate processes, assuming equivalent technological, legal, and social factors, can be made on the basis of annual process cost. There are, however, cases in which the economic comparison must be extended to include an analysis of potential profitability. If marketable products and/or byproducts are produced, the net income from sales may be sufficient to significantly reduce the net cost of the control process or even result in a profit for its operation. In either case, the elements which comprise profit would be evaluated and the optimum selected so as to minimize overall loss or to maximize profit.

It is also important to note that environmental protection processes are usually a portion of a larger processing system. As technology and process integration of protection techniques advance, it will be more difficult to isolate protection processes as being unique sub-systems. Thus the objective of design and operation will increasingly be addressed at the overall processing system level rather than at the sub-system level.

5.4 Selection of Estimation Method

As with other aspects of ecis preparation, the contractor must select an estimation method which yields adequate results within the resources available, and commensurate with the other aspects of the ecis.

Several estimating procedures exist. The choice of method will depend on required accuracy.

Proportional Method

Most preliminary cost estimation methods might be defined as largely an extrapolation process, that is, using a known cost to estimate an unknown cost.

Simplistic size ratios are often employed:

$$\frac{\text{Cost } x}{\text{Cost } 0} = \frac{\text{Size } x}{\text{Size } 0} \qquad (5.1)$$

Thus, if one ft^2 of building costs \$20, a 1000 ft^2 building would cost $\$20 \left(\frac{1000}{1}\right) = \$20{,}000$.

Such direct-ratio calculations do not properly address situations where a unit of a large facility might cost less (or more) than the same-sized unit in a smaller facility. To accommodate "economies of scale," empirically-determined exponents (other than 1) are often included in so-called "power-law" cost-ratio equations. For example, equation 5.1 might be revised:

$$\frac{\text{Cost } x}{\text{Cost } 0} = \left(\frac{\text{Size } x}{\text{Size } 0}\right)^{0.95} \qquad (5.2)$$

Continuing with the previous example, the 1000 ft^2 building would then cost $\$20 \left(\frac{1000}{1}\right)^{0.95} = \$14{,}000$.

In the previous examples, size was the independent variable, but time, location, efficiency, and other variables are often included in cost-ratio equations. Such equations are even used to relate dissimilar processes or pieces of equipment.

For example, knowing the cost of the building, an analyst might utilize a ratio calculation to easily estimate the cost of the sewers or the landscaping. Complex power law equations can include a variety of exponents, coefficients, and individual terms.

Multiple Regression Cost Equations

Multiple regression techniques are often used to prepare cost equations. It is unlikely that an ecis contractor would generate basic cost data, and subsequently prepare regression equations, but he might choose to regress existing cost data into an equation suitable for a particular ecis question. Note that Babcock (1973 and 1978) and Cohen (IIEQ 77/36) used the same basic data to arrive at different equations for control costs for sulfur dioxide and particulate matter. The former so-called "emcost" approach is the more general. It lumps together many of the costs and even discrete control techniques into single equations; an efficiency term is added. The latter (Cohen) approach retained more variables in the regression equations, and for particulate matter, separate equations were prepared for each individual control technique. The latter method doesn't include the efficiency variable.

The costs associated with differing efficiencies are of growing interest to IPCB and federal policy makers. The emcost method generated an efficiency term at the expense of accuracy and specificity. Obviously, both approaches have their uses, and still different regressions might be appropriate for other ecis questions.

The contractor has a wide choice in the amount of detail employed. For example, he might apply a single straightforward equation to estimate the cost of an entire large complex facility such as an oil refinery or electric power plant.

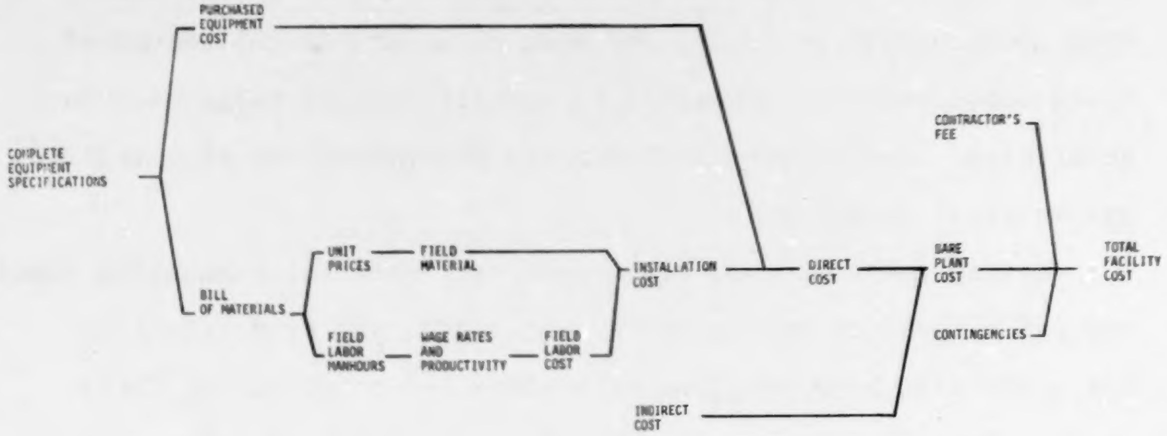
More specific, a single emcost equation can be used to estimate the total cost of a complete scrubber system including materials, handling and storage, waste disposal capital, operating and maintenance costs.

Definitive Cost Estimates

In contrast, the estimating procedure for preparing definitive estimates is very detailed and time consuming. In the definitive estimating method, drawings are prepared for all equipment items in the environmental protection flow processing facility, equipment foundations, buildings and structures, piping runs and outfall lines and all other cost engineering items required to definitively scope the work.

As shown in Figure 2, the task is first broken into two principal categories: collecting purchased equipment costs from vendors and determining the installation costs. For the evaluation of installation costs, further breakdown into material and labor categories is required.

Material takeoffs are prepared from the drawings. These material takeoffs consist of accurate, manually tabulated material quantities from the prepared drawings. Material quantities are tabulated for piping (e.g. fittings such as valves and elbows, tees, couplings), concrete (e.g. square feet of plywood forms for the foundations, pounds of steel reinforcements, sand, ready mix, etc.), instrumentation (e.g. pressure indicators, temperature indicators, flow recording controllers, pH indicators, etc.) and all the other field material quantities.



(Figure 2. Definitive Estimating Procedure)

These field material quantities, or bulk items as they are called in the construction trade, must be tabulated accurately so that a bill of material can be developed and material costs determined for each of the material quantities derived in the material takeoff.

In conjunction with determining these material quantity costs, labor manhours, derived from costs of similar and like type construction projects, are used to determine the amount of field labor manhours necessary to install each of these material quantities. Field labor manhours are determined for each individual material quantity.

Adding the purchased equipment cost, material quantities costs, and labor manhours multiplied by wage rates and productivities for a specific area (region) determines the total direct field costs. This direct cost is thus the total cost, including all material and labor costs, to install the equipment item on site.

Direct costs, however, do not include the costs associated with the contractor's engineering and construction overhead costs. These additional costs are called indirect costs. Prime contractor's engineering cost is estimated as a function of the job size, equipment item and equipment mix, process complexity and field material costs. The construction overhead cost is estimated as a function of the field labor activities. Collectively, the direct and indirect costs describe the bare plant cost. In addition, a negotiable contractor's fee must be determined. The contractor's fee is usually based on job size, status of the national economy, status of the contractor's shop, and negotiations with the client, operating company, or municipality.

Contingencies are applied to the bare plant cost and an associated contractor's fee determined or negotiated. Contingencies for the definitive estimate are usually quite low since all the major equipment items are defined.

The definitive estimating method is probably the most accurate method but still has its limitations. Site conditions may vary considerably during construction of the environmental protection facility, and labor productivity may drastically change during the actual construction phase. Definitive estimating is also very expensive and time consuming. As a result, the definitive estimate is usually prepared once and then only for those projects that have had a prior go-ahead from management.

Thus, there exists a hierarchy of estimation methods, each requiring different levels of resources and yielding different levels and types of accuracy. Figure 3 compares some alternatives; complexity increases moving down the table. Clearly, techniques and information are available to enable preparation of accurate cost estimates, even for extremely complex facilities such as integrated petrochemical complexes. Construction contractors who do not master the art do not long survive in the marketplace of the competitive bidding process. A scrubber or sewage treatment plant seems simple in comparison to a petrochemical complex.

Given the multitude of techniques and levels of sophistication, what level of resources should be devoted to cost estimation in a particular ecis? Review of previous ecis has revealed frequent overemphasis of cost estimation aspects.

Figure 3. Comparison of Estimation Methods

method	requirements		accuracy	applicability	references
	time	data			
factoring total facilities based on published financial characteristics	low	low	low	general	Hurter, 1977, pp 1-7
combined multi-variable regressions for facilities	low	low	low	general	Babcock, 1973, 1978 Equitable Environmental Health Association 1977, IIEQ 77/30
discrete multi-variable regressions for facilities	low	med	med	general	Cohen, 1977, IIEQ 77/36
factoring discrete equipment (conceptual)	med-high	high	high	less general	Hurter, 1977 Blecker and Cadman, 1973
definitive design	high	high	high	specific	Blecker and Cadman 1973

Two problems are apparent:

a. Detailed cost estimates for a specific plant at a specific site cannot be generalized statewide.

b. Cost estimate of whatever type contain far more detail than monetized estimates of environmental benefits or damages. Sometimes costs are reported to the penny, even when benefits may be uncertain by one or more orders of magnitude.

In both situations, ecis contractors should have settled for more-approximate cost estimates and allocated limited resources to other areas of the ecis. The goal is maximum elucidation of the total economic impact--not overdefinition of the cost aspect just because detailed cost estimates may be both feasible and straightforward. The availability of sophisticated tools is not in itself sufficient justification for employing a sophisticated cost estimation method.

An obvious conclusion at this point is that the contractor should utilize those methods listed in the upper part of Figure 3 unless there exists a very good justification for more rigor. When detailed methods are justified, the contractor should consider subcontracting the cost-estimation task to an individual or firm experienced in engineering cost estimation.

5.5 Adjustments to Capital and Operating Costs

Calculation of the capital costs and the first-year operating costs of pollution control equipment or process changes provides the basic estimates to which certain adjustments must be made. These adjustments include inflationary impacts, the handling of uncertainty in cost estimates, and the impact of technological innovation.

Inflation Adjustments

Continuing inflation of equipment and labor costs causes almost all published cost information to be out of date before it can be utilized in an ecis. Fortunately, various indices are routinely published which enable a contractor to readily extrapolate cost information from one date to another. For construction costs adjustment, the Engineering News Record construction cost index may be employed. Wage escalation for process industry workers can be derived from the Marshall Stevens Index. Evaluation factors for other classes of labor can be obtained from U.S. Bureau of Labor Statistics.

Inflation can confuse the interpretation of ecis results; arguments that "emission control is expensive now and inflation is likely to increase costs in the future" should be scrupulously avoided. All costs should be reported in terms of "present" dollars.

Uncertainty of Cost Estimates

Control costs can be estimated more accurately than benefits, but uncertainty remains. Two examples are included in a recent newsletter (Air/Water Pollution Report, November 28, 1977, pp. 474, 475): In a nuclear power plant controversy, EPA estimated that inclusion of cooling towers in the design "would probably add 77¢ to 85¢ to monthly utility bills." In contrast, the Carolina Power and Light Company estimated the cooling towers could add $1.14 per month to residential utility rates. In another controversy involving USA oil tankers, the Coast Guard estimated a cost of $1.2 billion over 15 years for segregated ballast retrofitting. In contrast, the American Petroleum Institute estimated $9.5 billion over 13 years.

For the first example involving cooling towers, the two estimates are in relatively close agreement. For the oil tankers, the divergence is extreme. For situations similar to the latter, the ecis should clearly present the estimation method so that the reader can easily identify the basic assumption(s) which caused the divergence. Further, such defined divergence should be reported as an error estimate for those ecis results which are likely to be used in cost-benefit comparisons, either in the ecis itself, or later by IPCB.

Within ecis resources, including data limitations, it seems most appropriate that the ecis contractor merely qualitatively estimate a standard error (single sigma) for each numerical result reported in the executive summary. Such an exercise at least may help indicate those results where uncertainty is large enough to reverse the conclusions. When uncertainty bands cannot be defined, sensitivity analysis should be employed to indicate the effects of possible errors on overall conclusions.

Technological Innovation

Frequently the choice of control strategy and cost estimation is strongly affected by what is considered to be the state-of-the-art in the prevention of emissions from a specific source class. State-of-the-art could be interpreted to mean:

1) the technology that is presently in widespread use;

2) the most advanced technology now offered by a pollution control equipment vendor;

3) control devices that have been proven feasible in demonstration projects.

The assumption that technologies in Class 2 or 3 will be used adds another element of uncertainty to the cost estimate. Little historical data will be available concerning installation costs and performance reliability for such units. Such uncertainty should not deter the contractor from investigating option 2, but an explicit statement regarding ranges of installation costs and performance should be included in the ecis. The contractor, except in extraordinary circumstances, should avoid the assumption of the use of technologies in their developmental stages.

5.6 Presentation of Results

The ecis contractor will by this stage have specified the degree of control required, the type of control utilized, the capital and operating costs of the strategy and the impact that elements of uncertainty have on the estimation process. The ecis contractor should now translate these results into three types of output:

1) a table of costs with their corresponding categories;

2) an annualized cost estimate (alternatively, a revenue requirement sufficient to pay for the pollution control costs);

3) the cost changes if greater or less control is required;

4) the relation between the revenue requirements and other financial indices of impacted industries, e.g. sales, net profit, capital expenditures.

In order to obtain a revenue requirement figure, the capital cost must be converted to an annual equivalent; that is, an amount of money which is paid every year would be capable of paying off the debt principal and interest of a loan sufficient in size to cover the initial capital cost. To the annual equivalent is added the operating, maintenance, utility costs, etc. in order to arrive at an annual revenue requirement (RR). The relationship is thus:

RR = (Capital Cost x Capital Recovery Factor) + Operating Cost (5.3) where capital recovery factor is a function of the industry cost of capital and the life of the equipment or process change. For an example of a revenue requirement calculation see IIEQ economic impact report on vehicle noise (R76/10).

The uncertainty with regard to the stringency of the final regulation requires that the contractor indicate to the PCB what effect alterations in the proposed regulation will have on cost. Thus, if a regulation requiring ± 10% control was considered, what impact would this have on costs. The relationship of the applicability of the regulation with respect to source size may also be useful to the PCB in weighing the merits of the specific design of a final proposal.

Finally, the cost estimates presented by themselves are difficult to translate into any meaningful measure of the impact on Illinois industry of a regulation. The revenue requirements should be compared to some measure of the impacted economic sectors' activity. Sales, wages, net profit and capital expenditures are four measures which might be used.

5.7 Sources of Cost Data

Cost data are available from a variety of sources.

A vendor, or consulting firm specializing in a specific control problem can often supply useful information very quickly. When using such data, try to obtain an indication of uncertainty and definition of which costs (capital, operating, taxes, etc.) are included in the estimate. Equipment vendors often do not include installation costs, much less operating costs.

Sometimes the most available estimate comes from the industry to be regulated. A sensitivity analysis should help indicate whether an independent cost estimate is warranted.

If the foregoing data sources are not fruitful, the contractor might try a general environmental abstracting service such as Pollution Abstracts. Beyond illustrative examples, environmental textbooks have not been found to be very useful sources of cost data.

More timely and useful are reports prepared for U.S. EPA. Various abstracts and searching services are summarized in the Reference Section (5.8). An example of a recent EPA report is that prepared by Pedco (Ponder, et al. 1976). Cost information in this report was used to derive the generalized emcost equations described in Babcock (1978).

Useful for definitive cost estimation, Blecker and Nicholas (1973) contains cost data for a large number of specific pieces of process equipment. The Cameron catalog, described in Section 5.2 also will contain cost information for individual pieces of process equipment.

CHAPTER SIX: PRICES, OUTPUT AND EMPLOYMENT

I. Introduction

This chapter indicates some alternative procedures for evaluating the effects of a proposed environmental regulation on prices, output and employment. The procedures assume that the revenue requirements generated by compliance to a proposed regulation have already been estimated. The focus of this chapter is to convert these revenue requirements to price, output or employment effects, given information regarding probable market response in the different economic sectors affected by the regulation. Primary effects are the product price, output and employment reactions of the entities directly imported by the regulation. For example, if a regulation refers to water quality of effluent from steel mills, then the cost of complying with the regulation will be reflected in changes in prices, output and/or employment by steel firms in Illinois. The changes in prices, output, and employment in the steel industry, however, induce changes in prices, output, and employment in other economic activities in Illinois through the usual market mechanisms. These are the secondary effects. Section II deals with primary effects. Section III deals with secondary effects.

The evaluation of price and employment impacts of environmental regulations is a complex undertaking. Even if the analyst determines the proper control strategy to be chosen and the costs of the strategy, the translation of costs to price, output and employment changes will be difficult. Among the factors which may complicate the analysis are: 1) The ability of a firm to pass environmental control costs onto the consumer may be hampered by regulatory restrictions (as in the case of utilities) or by consumer reluctance to purchase the product at significantly higher prices. 2) Illinois industries facing out-of-state competition may feel a price increase will significantly reduce their market share and therefore try to absorb increased costs. 3) If projected cost increases are significant enough, firms may consider relocation either in another part of the state where discharge standards are not as strict or to another state. 4) Industries doing business with firms which have increased prices in response to environmental control costs may in turn be forced to increase their prices. 5) Even if the state economy as a whole is not affected, local employment impacts may occur if a community economy is heavily dependent on a local firm severely impacted by a regulation.

In the sections that follow, market responses will be divided into two categories and labeled direct and secondary.

II. Direct Effects

The firms range of responses to increases in production costs may effect either prices or output levels or both. Firms will normally attempt set output where the cost of the last unit produced (marginal cost) equals the revenue derived from the sale of that unit (marginal revenue). Cost includes a normal profit or return on investment. If the cost curve is raised, for example, due to higher clean fuel costs, output is decreased and price rises. If the cost curve is raised far enough the firm will not produce at all since at no level of output will it be able to sell its product at a price that some consumers are willing to purchase it and at which the firm can earn an acceptable return on investment.

The ability to assess simultaneous changes in output and price requires knowledge concerning market condition and cost behavior. This information will normally not be available to the contractor. One possible way of proceeding under this condition is to define limiting cases of the firm's or industry's response to increased costs. Such responses include: 1. Pass on all costs to the consumer by raising prices, assuming no change in profits, output or employment in the impacted industry.

2. Absorb all costs by reducing the rate of return on capital, assuming no change in prices, output or employment in the industry.

3. Reduce other cost of production, possibly by reducing the quality of the product, in order to offset the pollution control costs.

4. Reduce output.

5. Shutdown or change the location of the industry.

1. Cost Pass Thru Pricing

The first case assumes that the firm incurring environmental costs feels that it can pass such costs to its customers by raising prices. Such a situation may occur in the regulated utilities or industries which have not traditionally been competitive with respect to price. The quantity demanded is not effected by price in this situation, e.g. residential sale of electricity.

Two calculations are presented for estimating price increases. Both rely on the assumption that the sales revenue of the firm or industry equals the total cost of production where cost includes depreciation and return on capital. Total cost of production defined in this manner, is equivalent to revenue requirements as defined in Chapter V. The simplest expression can be employed when the regulation will induce only increases in operating costs without any concommitant increase in capital expenditures. An example of such a regulation would be requirements to register toxic substances with the IEPA (R76-10). The bulk of the cost of the regulation arise from record keeping and clerical expenses. An expression can be written for the expected price increase: % price increase = (annual compliance cost) / (annual sales). Sales data classified by Standard Industrial Classification code (SIC) is available from the Census of Manufacturers.

A second cost-pass-thru pricing formula explicitly accounts for increased costs due to expenditures for equipment. The firm is assumed to have a target rate of return on invested capital. This approach to price estimation is similar to the one employed in calculating utility rate increases. Four categories of cost are considered:

1) depreciation and return on investment
2) operating and maintenance expense
3) ad valorem taxes
4) income tax disbursements

1) Depreciation and return on investment. This cost is estimated from a "capital recovery formula"

$$CR = (P-S)\ CRF\ (i,n) + iS$$

where P is the purchase price of equipment

S is the salvage value at the end of the equipment lifetime
i is the required rate of return
n is the life of the equipment
CRF ( ) is a factor which converts the initial outlay to an equivalent annual cost. (A table of such factors can be found in most elementary financial management texts.)

2) Operating and maintenance costs

These are costs obtained from vendor estimates, firms already using such equipment, trade publications, etc.

3) Ad valorem tax

These are non-income related taxes such as property taxes. For preliminary calculations use 2% to 4% of the purchase price of the equipment.

4) Equivalent annual tax disbursement

To obtain an estimate of this, a tax factor is multiplied by P. The tax factor is

$$TF = \left[e/(1-e)\right] \left[(a-bc)\right] \left[(s/p) + (1-(s/p)) \quad (1-CRF(b,n)\right]$$

where e is the effective income tax rate
a is the target rate of return on equity
b is the interest on borrowed money
c is the fraction of equipment financed by borrowing
n is the life of equipment
CRF ( ) is the capital recovery factor which converts the value of an asset being depreciated on a straight line basis over n years to an equivalent annualized value.

For preliminary calculations a TF of .08(1-CRF) can be used. Thus:

tax disbursement = (TF) (P)

The revenue requirement equals the sum of these four elements. Once the annualized revenue requirement is calculated, the percentage price increase is given by

%p = revenue requirement/annual sales

For industries which have a large percentage of firms filing financial statements, data on equity-borrowing ratios (C) and rates of return on equity (a) can be obtained from "Key Business Ratios", Dunn and Bradstreet and the "Almanac of Business and Industrial Ratios.

2. Absorb Costs by Reducing Target Rate of Return

If the firm does not feel it can raise prices because of the potential that demand for its products would significantly decrease (i.e., farmers or others in a market where goods are perfect substitutes for one another), it may decide to absorb the costs by lowering its targeted rate of return. This strategy would absorb costs without a change in price or outputs.

The reduction in rate of return can be approximated by

$$r_2 = r_1 - \frac{\text{annual revenue requirement of pollution control}}{\text{Invested capital in plant and equipment}}$$

where r_1 is the rate of return on invested capital before the regulation.

r_2 is the rate after the regulation

3. Offset Pollution Control Costs by Reduction in Product Quality

Reduction on the rate of return on invested capital is only one cost offset policy. Other costs could be reduced by use of inferior materials, reduction in quality control standards or use of lower grade labor. The intent of such policies is to maintain price and output without sacrificing the present rate of return. The firm takes the risk that "quality" offsets will alter the perception of the product from the consumer's viewpoint. If this happens, the firm may experience a shift in the demand which ultimately results in an output and price shift, regardless of their efforts to avoid it. In effect, a new product is being offered and must face a new market situation.

An assessment of the potential of this firm response and market reaction in difficult. There is no simple formula to indicate the potential demand shift. Two limiting cases can be defined. One case is a situation where the consumer does not alter demand so that price, output, return on capital and employment remain essentially the same. In the second case, the price falls to a level commensurate with a marketed good of inferior quality, i.e., if Lincoln Continentals were built like Toyotas, they would eventually sell for the same price.

Ordinarily quality reductions would not take place unless the manufacturer considered that demand would for the most part be sustained. In assessing the potential of this reaction to pollution control costs, the ecis contractor faces the task of analyzing the extent of potential cost savings by quality reduction and compare these savings with revenue requirements generated by the regulation. The potential of consumer reaction to such a cost offset policy should at least be qualitatively discussed with regard to the substitutibility of competing products and product loyalty.

4. Reduce Output and Employment

There are cases where the firms or an industry will reduce output without changing their product price to the consumer or necessarily reducing quality. If the consumers are highly sensitive to price and can purchase from other sources, the firm may not be able to raise prices. If producing at a lower output reduces average or unit costs, then the firm may be required to do so to offset increased pollution control costs.

A second possible output reduction condition might occur when transportation costs are a significant portion of the cost to the consumer of purchasing the product. If consumers have a fixed total price that they are willing to pay, one way of offsetting increased pollution control costs is to reduce transportation costs. This reduction can be achieved by serving closer markets, but as a result, output will be reduced.

These output changes may be calculated in a number of ways.

1. Capacity Change Method

If the pollution control measure causes the capacity of the plant to be reduced, then engineering considerations may be used in estimating output impacts. Examples of such output responses are the required use of scrubbers on power plants which decrease the net generation of power output due to the energy requirements of the scrubber itself. Similarly, nighttime noise limitations may restrict 3rd shift operations at a forging plant. Episode control regulations may require temporary shutdowns which cause output reductions which cannot be made up at a later time. Of course, for the analyst to make use of the capacity technique, the firms involved should be running at or near capacity; capacity should have a clearly defined meaning and the capacity impact of the regulation be assessable in a defensible manner.

2. Market Area Decrease

A second possible method for estimating output reductions is in situations in which transportation costs represent a significant fraction of the cost of the product to the consumer. Output reductions occur if the firm raises its FOB prices to cover environmental costs, because those customers on the "edge" of the producers market now find it cheaper to buy from a competing production center. For example, suppose Illinois coal were sold as far away as Tennessee under present pricing policies. A coal mine land rehabilitation tax is then levied and Illinois companies raise their prices to cover this cost. The Tennessee firms buying Illinois coal may then switch to competitors, say in Montana, whose FOB price plus transportation costs are now lower than those offered by the Illinois coal companies. However, customers in Kentucky might still find it advantageous to purchase Illinois coal because transportation costs are significantly lower than Montana coal.

A method of making a crude estimate of the decrease in market area and output would include the following steps:

1) Determine whether transportation costs are a significant fraction of the price of the product in question.

2) Determine the limits of the trading distance for the Illinois product. The Census of Transportation and data from professional

organizations will aid in making this determination. An approximate unit cost of transporting the product should also be made in terms of cost per ton-mile or an equivalent.

3) Equate maximum existing transport cost per ton at the limit of the existing market area with the sum of a new maximum transportation cost per ton and the environmental control costs divided by existing output.

4) Solve for the new maximum transport costs per ton and divide this number by the cost per ton mile to obtain the new maximum market radius.

5) Output reductions will be equal to existing sales made in areas beyond the new maximum estimated radius.

Thus, if the existing market radius is 500 miles, the cost per ton-mile is \$.01, environmental control costs are \$1,000,000 and present output is one million tons, the calculation would be as follows:

500 miles X (\$.01/ton-mile) = New maximum unit transport cost + (environmental control cost/output)

New maximum unit transport cost =

\$5/ton - \$1,000,000/1,000,000 tons = \$4/ton

This is equivalent to a maximum market radius of 400 miles. Sales would be lost in the area between 400 and 500 miles. This yields an upper bound of the market reduction effects.

3. General Case of Output Reduction

The cases presented in 1 and 2 are really particular examples of how firms may react when costs increase. For the most general case, if the firms marginal cost of production, i.e. cost of producing the last unit, rises, then output will decline and price will rise. If cost and demand functions for an industry have been estimated, then it is possible to estimate these simultaneous changes. Estimating these functions will, however, normally be outside the scope of an ecis study.

One special case that may be analyzed without statistical cost functions is the situation in which the average cost of production equals the cost of producing the last unit and some range for price elasticity is known. Price elasticity is a measure of the sensitivity of demand to price changes. It is formally defined as the % change in demand resulting from a 1% change in price (assuming the other factors affecting demand do not change). A decrease in quantity can be calculated as

% decrease in quantity = (price elasticity) (% increase in price)

where % increase in price is computed by cost pass thru method.

In some cases, published studies of the price elasticity of the product exist, but frequently this information is not available and its estimation will be beyond the scope of the impact study. If there is a high price elasticity of demand, firms may not pass thru the full cost of the regulation.

Several indirect indications of whether costs would be passed thru may aid the analyst in adjusting the price calculations for possible demand effects. A small survey of firms within the state or secondary trade publications data may indicate the perceived importance of out-of-state competition. A high transportation costs to selling price ratio might indicate that a firm's local market area will not be greatly affected by outside competition even if prices were raised. Measures of industrial concentration will also provide some guidance on the extent of competition.

4. Plant Shutdown

In the previous description of firm responses, it was implicitly assummed that the firm would continue to operate after adjustment to prices or output. In the short run the firm might continue to operate even if it were operating at a loss. If revenues are greater than its variable costs, i.e. those costs that vary with output levels, then the firm either makes a profit or at least can make some contribution to paying fixed costs from the excess of revenues over variable costs. If the firm's revenues do not meet his variable costs, however, the owner might as well shut down. By continuing to operate in the red he will lose all of his fixed costs plus an additional portion of his variable costs, whereas, if he shuts down he will lose only his fixed costs.

In notational form the plant manager facing increased cost because of pollution control requirements will shut down if:

$$R < VC + PC$$

Where:

R = Total Annual Revenues

VC = Variable Costs = Expenditures that could be avoided by shutting down

PC = Pollution control costs - also variable

Another convenient rule-of-thumb is that a plant will be kept open as long as the rate of return on invested assets exceeds some required minimum.

If one assumes that all future years will be equivalent to the coming year, the decision in notational form becomes: A plant will be shut down if:

$$\frac{P - PC(1-t)}{S + PCI}$$

Where:

r = Required rate of return

P = Annual profits after taxes without pollution control expenses

PC = Annual pollution control costs, or that portion which is not passed on in higher costs.

S = Salvage value of the plant

PCI = Additional investment required to meet pollution control requirements

t = Marginal income tax rate

In effect the shutdown decision sets a limit to the reduction in rate of return that the manager is willing to tolerate.

III. Indirect Price and Employment Effects

The price or output impacts in industries directly affected by regulation may have secondary impacts on industries purchasing goods from them. Two methods are presented here which are designed to assess these indirect impacts. The first is input-output analysis. An input-output model described in the next section, was developed for use by IIEQ contractors in a IIEQ sponsored study. Since the model considers statewide inter-industry-purchases of goods and employment effects, its use should be restricted to evaluation of regulations affecting a large segment of Illinois industry rather than, for example, a regulation which may severely impact employment of a single plant in one Illinois town. The measurement of indirect employment effects in such a local situation may be of great importance, particularly if the town's economy depends on a single industry, but the Bureau of Budget model would not be sensitive to such impacts.

A second method, economic base study techniques, is more applicable to the local impact case. This technique is sensitive to the relative significance of reductions in employment from different industries in the vicinity of a single impacted firm. Economic base studies are discussed in the second section.

IV. Input-Output Analysis

Input-output analysis operates through a division of the economy into a number of industrial sectors, final demand sectors and primary input sectors. The industrial sectors are comprised of aggregations of firms producing similar products. These aggregations are based upon the Standard Industrial Code.

Referring to Figure 1, we may assume that it was appropriate to aggregate firms into just five industrial sectors: 1) agriculture, 2) mining, 3) electrical engineering, 4) business services, and 5) transportation. The 5 x 5 upper left-hand section of the table in Figure 1 is known as the interindustry transactions matrix. By looking across a row, we can determine the disposition of sales from one industry to others in the state. The column entries may be regarded as the distribution of purchases by the industry at

Input-Output Transactions Table

(All entries in $ Millions)

	TO	Agric.	Mining	Elec. Eng.	Bus. Serv.	Trans.	House-holds	State Gov.	Invest-ment	Fed. Gov.	Exports	Total Output
		1	2	3	4	5	6	7	8	9	10	11
FROM												
Agric.	1	21	-	9	3	-	30	10	0	5	22	100
Mining	2	1	8	7	29	-	25	5	2	-	23	100
Elec. Eng.	3	3	20	-	50	7	5	1	4	4	6	100
Bus. Serv.	4	31	2	38	-	3	12	2	-	11	1	100
Trans.	5	10	25	26	1	4	9	6	2	11	5	100
Value Added	6	20	40	10	17	40	2	49	4	9	-	
Import	7	14	5	10	-	46	77	20	-	-	-	
Total Input	8	100	100	100	100	100	100	93	12	40	67	

the top of the column from all the industries below. Thus, sector 4, business services, purchases $3m from agriculture, $29m from mining, $50m from electrical engineering and $1m from transportation.

In addition to purchases from other industries in the region, state or nation, an industrial sector will require labor input and may also require goods and services from outside the region, state or nation. These entries are shown in rows 6 and 7 and are referred to as primary sectors. Value added (row 6) includes wages and salaries, dividends, profits and undistributed income. It is the balancing item in the accounting framework since, by definition, total input must equal total output. i.e. sales must equal purchases. Transactions between industries outside the geographic area of the model are shown in the imports row (row 7). In regional or state models, a distinction is sometimes made between imports from other regions or states and foreign imports. The final row represents the summation of total inputs (outputs).

Industries also sell goods and services to consumers, government and to industries in other geographic areas. These transactions are referred to as final demand activities. Column 6 shows transactions between the industries at the left and the household sector. In input-output analysis, sales from industries to wholesalers-retailers-consumers are shown as direct sales to consumers. Wholesaler and retailer markups are shown as purchases of services by the consumer from the wholesale and retail trade sectors.

As a basis for operations, a 1972 Illinois input-output model is utilized. The model essentially consists of estimates of the interindustry and sector trading coefficients. The primary model is derived from a 1967 U.S. input-output model which was modified to represent Illinois and updated to 1972 by a research team in the Illinois Bureau of the Budget.

If the contractor believes that an input-output model should be used, he should organize pollution control costs by 3 or 4 digit SIC classification. This data will be transmitted to the Bureau of the Budget by IIEC staff.

The model will then be run by BOB personnel to assess secondary impacts of the regulation. Consultation with BOB or IIEC personnel should take place before collection of the appropriate cost data. BOB personnel assistance will be available to the contractor to assist them in interpreting the output of the model.

V. Economic Base Analysis

Economic base analysis suggests that the growth of a region depends upon the growth of its export sector; the implication being that expansion of demand external to the region is the driving force behind growth within the region. Thus, an increase in the economic base of the region (i.e., all the exportable goods and services produced therein) sets off a multiplier process of growth within the local or secondary sectors of the regional economy. Using this theory as a foundation, economists and regional analysts have attempted to measure the relationship between exogenously determined growth in a region's basic (i.e., export) sector and the indirect and income-induced effects that this growth makes possible within the local (i.e.,secondary) sectors.

The specification of multipliers derived from economic base theory has taken many forms. In its most crude form, the employment multiplier for a given region is derived, using least-squares estimation, from the following equation:

$$E_s = a + bE_p$$

That is, secondary employment is postulated to be a linear function of primary (i.e., basic) employment. In practice, this relationship is fitted by first segmenting the industries of a particular region on the basis of whether their employment is, or is not, sustained by an inflow of external receipts. Employment in industries that are sustained by local receipts is considered an exogenous variable for the purpose of model specification; that is, its level affects local employment but is not influenced by it. While the separation of regional industries on the basis of this criterion can range from easy to extremely difficult, there is evidence that whenever the analyst is in doubt of which category to assign a certain industry, no bias will result if he assigns its employment to the endogenous (i.e., secondary employment) category.

The previous equation, which reveals the increase in secondary employment given a unit increase in primary (i.e., exogenous) employment, is greatly oversimplified. Implicit in this specification is the assumption that an increase in employment in any primary industry will have an identical impact on local secondary employment. Thus, a unit increase in manufacturing employment will have the same effect, "b", on secondary employment as a unit increase in transportation employment. Further, the relationship between primary and secondary employment is assumed to be constant, regardless of the size of the exogenous employment increase. This assumption ignores the existence of scale economies in the endogenous sector. Realistically, it can be expected that as larger exogenous increases in primary employment occur, regional support employment will increase at a decreasing rate. Finally, the character of the community receiving the exogenous employment will have a marked influence on the multiplier. That is, if the community is located close to a regional trade center, secondary employment increases may be much smaller than if the increase in primary employment should occur in relatively isolated localities. Such localities would have to provide support activities without relying on regional trade centers to absorb the increased demand. These are among the most difficult problems associated with the simple specification secondary employment equation.

Data for employment by industry by county can be obtained from County Business Patterns or the office of Economic and Business Development of the State of Illinois. The analyst will be required to make judgment regarding what employment is "basic" or "non-basic" in order to estimate a local multiplier.